CHAPTER 5: ENGINEERING ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

A	present value of future core losses ($/watt)
Al	aluminum
ANOPR	Advance Notice of Proposed Rulemaking
ANSI	American National Standards Institute
B	present value of future coil losses ($/watt)
BIL	basic impulse insulation level
CSA	Canadian Standards Association
Cu	copper
DL	design line (followed by a number indicating which design line)
DOE	United States Department of Energy
H-O DR	laser-scribed M3 core steel
Hz	hertz
kV	kilovolt
kVA	kilovolt-ampere (transformer size rating)
LL	load losses
M*	M2, M3, M4, M6 - grade of core steel
NEMA	National Electrical Manufacturers Association
NCI	Navigant Consulting, Inc. (formerly Arthur D. Little, Inc.)
NL	no-load losses
NOPR	Notice of Proposed Rulemaking
OPS	Optimized Program Service, Inc.
ORNL	Oak Ridge National Laboratory
PC	product class
SA1	Metglas amorphous core material
SEC	Securities and Exchange Commission
TL	total losses
US	United States
V	volts
Y	wye-type transformer terminal connection
ZDMH	mechanically scribed, deep-domain refined core steel
Φ	phase

CHAPTER 5: ENGINEERING ANALYSIS

5.1 INTRODUCTION

This chapter provides the technical support documentation on the engineering analysis, evaluating both liquid-immersed and dry-type distribution transformers. The purpose of the engineering analysis is to estimate the relationship between the manufacturer's selling price of a transformer and its corresponding efficiency rating. This relationship serves as the basis for the subsequent cost-benefit calculations for individual consumers, manufacturers, and the nation (see Chapter 8, Life-Cycle Cost and Payback Period Analyses).

5.2 STRUCTURING THE ENGINEERING ANALYSIS

As discussed in the market and technology assessment (Chapter 3), distribution transformers are classified by their insulation type (liquid-immersed or dry-type), the number of phases (single or three), the primary voltage (low-voltage or medium-voltage for dry-types) and the basic impulse insulation level (BIL) rating (for dry-types). Following this convention, the Department developed ten product classes, shown in Table 5.2.1. These product classes were adapted from National Electrical Manufacturers Association's (NEMA) TP 1 classification system, though they do not follow the classification system precisely. NEMA's TP 1 classifies medium-voltage, dry-type distribution transformers into two product classes, ≤60 kilovolt (kV) BIL and >60 kV BIL. Based on input from manufacturers, the Department elected to increase the differentiation of medium-voltage, dry-type transformers, and create three product classes of BIL ratings: 20-45 kV BIL, 46-95 kV BIL and ≥96kV BIL (see section 3.3).

Within each of these product classes, distribution transformers are further classified by their kilovolt-ampere (kVA) rating. These kVA ratings are essentially size categories, indicating the power handling capacity of the transformers. Due to the construction methods and material properties, efficiency levels vary by both product class and kVA rating. For NEMA's TP 1-2002[a], there are 99 kVA ratings across all the product classes (see section 3.7.1). For the Department, because of the greater degree of differentiation around the BIL rating in medium-voltage dry-type transformers, there are 115 kVA ratings across all the product classes, as shown in Table 5.2.1

[a] NEMA's TP 1-2002 can be found online at www.nema.org.

Table 5.2.1 Product Classes and Number of kVA Ratings

Distribution Transformer Product Class	kVA Range	Number of kVA Ratings
1. Liquid-immersed, medium-voltage, single-phase	10-833	13
2. Liquid-immersed, medium-voltage, three-phase	15-2500	14
3. Dry-type, low-voltage, single-phase	15-333	9
4. Dry-type, low-voltage, three-phase	15-1000	11
5. Dry-type, medium-voltage, single-phase, 20-45 kV BIL	15-833	12
6. Dry-type, medium-voltage, three-phase, 20-45 kV BIL	15-2500	14
7. Dry-type, medium-voltage, single-phase, 46-95 kV BIL	15-833	12
8. Dry-type, medium-voltage, three-phase, 46-95 kV BIL	15-2500	14
9. Dry-type, medium-voltage, single-phase, $\geq$96 kV BIL	75-833	8
10. Dry-type, medium-voltage, three-phase, $\geq$96 kV BIL	225-2500	8
	Total	115

The Department recognized that it would be impractical to conduct a detailed engineering analysis of the manufacturer's selling price-efficiency relationship on all 115 kVA ratings, so it sought to develop an approach that simplified the analysis while retaining reasonable levels of accuracy. The Department consulted with industry representatives and transformer design engineers, and developed an understanding of the construction principles for distribution transformers. It found that many of the units share similar designs and construction methods. Thus, the Department simplified the analysis by creating 13 engineering design lines, which group together kVA ratings based on similar principles of design and construction. These 13 design lines subdivide the product classes, to improve the accuracy of the engineering analysis. These 13 engineering design lines differentiate the transformers by insulation type (liquid-immersed or dry-type), number of phases (single or three), and primary insulation levels for medium-voltage dry-type (three different BIL levels).

The Department then selected one unit from each of the engineering design lines for study in the engineering analysis and the LCC analysis (see Chapter 8), reducing the number of units for analysis from 115 to 13. The Department then extrapolates the results of its analysis from the unit studied to the other kVA ratings within that same engineering design line. This extrapolation is conducted in the National Impacts Analysis (see Chapter 10). The technique used to extrapolate the findings on the representative unit to the other kVA ratings within a design line is referred to as "the 0.75 scaling rule." This rule states that, for similarly-designed transformers, costs of construction and losses scale to the ratio of kVA ratings raised to the 0.75 power. The relationship is valid where the optimum efficiency loading points of the two transformers being scaled are the same. An example of how this scaling is applied appears in section 5.2.1 of this chapter. A technical discussion on the derivation of the 0.75 scaling rule appears in Appendix 5-B.

Table 5.2.2 presents the Department's 13 design lines and the representative units selected from each engineering design line for analysis. Descriptions of each of the design lines and the rationale behind the selection of the representative units follow Table 5.2.2.

Table 5.2.2 Engineering Design Lines (DL) and Representative Units for Analysis

PC*	DL	Type of Distribution Transformer	kVA Range	Representative Unit for this Engineering Design Line
1	1	Liquid-immersed, single-phase, rectangular tank	10-167	50 kVA, 65˚C, single-phase, 60Hz, 14400V primary, 240/120V secondary, rectangular tank
	2	Liquid-immersed, single-phase, round tank	10-167	25 kVA, 65˚C, single-phase, 60Hz, 14400V primary, 120/240V secondary, round tank
	3	Liquid-immersed, single-phase	250-833	500 kVA, 65˚C, single-phase, 60Hz, 14400V primary, 277V secondary
2	4	Liquid-immersed, three-phase	15-500	150 kVA, 65˚C, three-phase, 60Hz, 12470Y/7200V primary, 208Y/120V secondary
	5	Liquid-immersed, three-phase	750-2500	1500 kVA, 65˚C, three-phase, 60Hz, 24940GrdY/14400V primary, 408Y/277V secondary
3	6	Dry-type, low-voltage, single-phase	15-333	25 kVA, 150˚C, single-phase, 60Hz, 480V primary, 120/240V secondary, 10kV BIL
4	7	Dry-type, low-voltage, three-phase	15-150	75 kVA, 150˚C, three-phase, 60Hz, 480V primary, 208Y/120V secondary, 10kV BIL
	8	Dry-type, low-voltage, three-phase	225-1000	300 kVA, 150˚C, three-phase, 60Hz, 480V Delta primary, 208Y/120V secondary, 10kV BIL
6	9	Dry-type, medium-voltage, three-phase, 20-45kV BIL	15-500	300 kVA, 150˚C, three-phase, 60Hz, 4160V Delta primary, 480Y/277V secondary, 45kV BIL
	10	Dry-type, medium-voltage, three-phase, 20-45kV BIL	750-2500	1500 kVA, 150˚C, three-phase, 60Hz, 4160V primary, 480Y/277V secondary, 45kV BIL
8	11	Dry-type, medium-voltage, three-phase, 46-95kV BIL	15-500	300 kVA, 150˚C, three-phase, 60Hz, 12470V primary, 480Y/277V secondary, 95kV BIL
	12	Dry-type, medium-voltage, three-phase, 46-95kV BIL	750-2500	1500 kVA, 150˚C, three-phase, 60Hz, 12470V primary, 480Y/277V secondary, 95kV BIL
10	13	Dry-type, medium-voltage, three-phase, 96-150kV BIL	225-2500	2000 kVA, 150˚C, three-phase, 60Hz, 12470V primary, 480Y/277V secondary, 125kV BIL

* PC means Product Class (see Chapter 3 of the TSD). The analytical results for PC5, PC7 and PC9 are calculated based on the results for their three-phase counterparts. The Department did not select any representative units from the single-phase medium-voltage product classes (PC5, PC7 and PC9) because of their low sales volume.

Liquid-immersed transformers are divided into five engineering design lines, based on their tank shape, number of phases and kVA ratings. The Department believes that this breakdown enables the analysis to identify and capture a more accurate representation of the manufacturer's selling price and efficiency relationship. Dry-type distribution transformers are broken into eight engineering design lines, primarily according to their BIL levels. The Department believes this level of disaggregation is necessary to capture important differences in the price-efficiency relationship, particularly as the BIL level varies. For example, a 300 kVA, three-phase, dry-type unit could be classified in design lines 8, 9, 11, or 13 depending on whether the BIL rating is 10 kV (low-voltage), 20-45 kV, 46-95 kV, or 96-150 kV.

For design lines 9 through 13, the representative units selected for some of the dry-type design lines may not be the standard BIL levels associated with a given primary voltage. The

Department selected a slightly higher BIL level for the representative units from these design lines to ensure that any minimum efficiency standard would not excessively penalize customers purchasing transformers at higher BIL ratings within the range. For example, a 300 kVA with a 4160V primary is called a "5kV class" transformer and would normally be built with a 30kV BIL level. However, customers may also choose to order this transformer with 45kV BIL or 60kV BIL. If the candidate minimum efficiency standard were set based upon a 30kV BIL, it may not be possible to achieve that same efficiency rating for customers ordering 60kV BIL. Thus, the Department evaluated the middle BIL level (in this example, 45kV BIL), making it slightly easier to comply for a lower BIL, and not too difficult (or impossible) for the higher BIL.

The remainder of this section discusses each of the thirteen engineering design lines, providing a description and explanation of the transformers covered.

Design Line 1. This is the basic, high-volume line for rectangular-tank, single-phase, liquid-immersed distribution transformers, ranging from 10 kVA to 167 kVA. Transformers in this design line typically have BIL levels ranging from 30 kV to 150 kV, a tap configuration of four 2½ percent taps, two above and two below the nominal, a primary voltage less than 35 kV and a secondary voltage less than or equal to 600 Volts (V).

The representative unit selected for design line 1 is a 50 kVA pad-mounted unit, as this is a high shipment volume rating, and is approximately the middle of the kVA range for this design line (10 kVA, 15 kVA, 25 kVA, 37.5 kVA, 50 kVA, 75 kVA, 100 kVA and 167 kVA). Engineering design considerations and manufacturing differences led to the placement of 250 kVA and higher rated units in design line 3.

Design Line 2. This is the basic, high-volume line for round-tank (pole mounted), single-phase, liquid-immersed distribution transformers, ranging from 10 kVA to 167 kVA. Although some manufacturers tend to employ the same basic core/coil design for design line 1 and design line 2, others may have design differences between pad-mounted and pole-mounted transformers. The Department decided to analyze these two types of distribution transformers separately for the engineering and Life Cycle Cost (LCC) analysis. Transformers in this design line typically have BIL levels ranging from 30 kV and 150 kV, a tap configuration of four 2½ percent taps, two above and two below the nominal, a primary voltage less than 35 kV and a secondary voltage less than or equal to 600 Volts (V).

The representative unit selected design line 2 is a 25 kVA pole-mounted unit, as this is a high-volume rating for pole-mounted transformers, and is on the lower end of the kVA range for this design line (10 kVA, 15 kVA, 25 kVA, 37.5 kVA, 50 kVA, 75 kVA, 100 kVA and 167 kVA). Engineering design considerations and manufacturing differences led to the placement of 250 kVA and higher rated units in design line 3.

Design Line 3. This design line groups together single-phase, round-tank, liquid-immersed distribution transformers, ranging from 250 kVA to 833 kVA. Together, design lines 1 through 3 cover all the single-phase, liquid-immersed units (there are no standard kVA ratings between 167 and 250 kVA). Transformers in this design line typically have BIL levels ranging from 30 kV to 150 kV, a tap configuration of four 2½ percent taps, two above and two below the nominal, a primary voltage less than 35 kV and a secondary voltage less than or equal to 600 Volts (V).

The representative unit selected for design line 3 is a 500 kVA round-tank, as this is a common rating and occurs in the middle of the kVA range for this design line (250 kVA, 333 kVA, 500 kVA, 667 kVA, and 833 kVA). Although high currents result with 277 Volt secondary at the larger kVA ratings, high-current bushings are available, and a market does exist for these transformers.

Design Line 4. Design line 4 represents rectangular tank, three-phase, liquid-immersed distribution transformers, ranging from 15 kVA to 500 kVA. Transformers in this design line typically have BIL levels ranging from 30 kV to 150 kV, a tap configuration of four 2½ percent taps, two above and two below the nominal, a primary voltage less than 35 kV and a secondary voltage less than or equal to 600 Volts (V).

The representative unit selected for design line 4 is a 150 kVA transformer, as this is a common rating in this design line and occurs approximately in the middle of the kVA range (15 kVA, 30 kVA, 45 kVA, 75 kVA, 112.5 kVA, 150 kVA, 225 kVA, 300 kVA, and 500 kVA).

Design Line 5. Design line 5 represents rectangular tank, three-phase, liquid-immersed distribution transformers, ranging from 750 kVA to 2500 kVA. Together, design lines 4 and 5 cover all the three-phase, liquid-immersed units (there are no standard kVA ratings between 500 and 750 kVA). Transformers in this design line typically have BIL levels ranging from 95 kV to 150 kV, a tap configuration of four 2½ percent taps, two above and two below the nominal, a primary voltage less than 35 kV and a secondary voltage less than or equal to 600 Volts (V).

The representative unit selected for this design line is a 1500 kVA transformer, as this is a common rating in this size range, and occurs in the middle of the kVA range for this design line (750 kVA, 1000 kVA, 1500 kVA, 2000 kVA, and 2500 kVA).

Design Line 6. Design line 6 represents single-phase, low-voltage, ventilated dry-type distribution transformers, ranging from 15 kVA to 333 kVA. Transformers in this design line typically have BIL ratings of 10 kV and a "universal" tap arrangement, meaning six 2½ percent taps, two above and four below the nominal. The Department selected this tap arrangement based on recommendations from manufacturers who produce transformers at these ratings. The primary and secondary voltages are both 600 V or below.

The representative unit selected for design line 6 is 25 kVA, as this is a common rating in this size range, and occurs toward the low end of the kVA ratings for this design line (15 kVA, 25 kVA, 37.5 kVA, 50 kVA, 75 kVA, 100 kVA, 167 kVA, 250 kVA, 333 kVA).

Design Line 7. Design line 7 represents three-phase, low-voltage, ventilated dry-type distribution transformers, ranging from 15 kVA to 150 kVA. Because the kVA range of three-phase ratings is broad and construction techniques differ, the Department split the range of three-phase, low-voltage, dry-type transformers into design line 7 and design line 8, so the engineering differences in core-coil design and manufacturing would be more readily apparent. Transformers in this design line typically have BIL ratings of 10 kV and a "universal" tap arrangement, meaning six 2½ percent taps, two above and four below the nominal. The primary and secondary voltages are both 600 V or below.

The representative unit selected for design line 7 is a 75 kVA transformer, as this is a common rating in this size range, and occurs in the middle of the kVA ratings for this design line (15 kVA, 30 kVA, 45 kVA, 75 kVA, 112.5 kVA, 150 kVA).

Design Line 8. Design line 8 represents three-phase, low-voltage, ventilated dry-type distribution transformers, ranging from 225 kVA to 1000 kVA. Transformers in this design line typically have BIL ratings of 10 kV and a "universal" tap arrangement, meaning six 2½ percent taps, two above and four below the nominal. The primary and secondary voltages are both 600 V or below.

The representative unit selected for this design line is a 300 kVA transformer, as this is a common rating in this size range, and occurs toward the lower end of the range of kVA ratings included in this design line (225 kVA, 300 kVA, 500 kVA, 750 kVA, and 1000 kVA).

Design Line 9. Design line 9 represents three-phase, medium-voltage, ventilated dry-type distribution transformers, ranging from 15 kVA to 500 kVA. To accommodate the broad kVA range and to allow for engineering differences in construction principles and associated costs, the Department split the three-phase, medium-voltage, dry-type units into design lines 9 and 10. Transformers in this design line typically have primary voltages less than or equal to 5 kV with a BIL rating between 20 kV and 45 kV. The secondary voltage is less than or equal to 600 V and the tap arrangement is typically four 2½ percent taps, two above and two below the nominal.

The representative unit selected for design line 9 is 300 kVA, as this is a common rating in this size range, and occurs near the high end of the kVA ratings for this design line (15 kVA, 30 kVA, 45 kVA, 75 kVA, 112.5 kVA, 150 kVA, 225 kVA, 300 kVA, and 500 kVA).

Design Line 10. Design line 10 represents three-phase, medium-voltage, ventilated dry-type distribution transformers, ranging from 750 kVA to 2500 kVA. Transformers in this design line typically have primary voltages less than or equal to 5 kV with a BIL rating between 20 kV and 45 kV. The secondary voltage is less than or equal to 600 V and the tap arrangement is typically four 2½ percent taps, two above and two below the nominal.

The representative unit selected for this design line is a 1500 kVA transformer, as this is a common rating, and occurs in the middle of the kVA range for this design line (750 kVA, 1000 kVA, 1500 kVA, 2000 kVA, and 2500 kVA).

Design Line 11. Design line 11 represents three-phase, medium-voltage, ventilated dry-type distribution transformers, ranging from 15 kVA to 500 kVA. This design line parallels design line 9, with a higher primary insulation level, 46 kV to 95 kV BIL. Because dry-type transformer designs and, more importantly, the efficiency of those designs, is strongly influenced by changes in BIL, the Department considered these higher BIL ratings separately. The typical tap arrangement is four 2½ percent taps, two above and two below the nominal. The primary voltage is typically less than or equal to 15 kV and the secondary voltage is less than or equal to 600 V.

The kVA ratings in design line 11 are 15 kVA, 30 kVA, 45 kVA, 75 kVA, 112.5 kVA, 150 kVA, 225 kVA, 300 kVA and 500 kVA. The shipments for this design line are concentrated in the

225 kVA through 500 kVA rating; therefore, the Department selected the 300 kVA rating as the representative unit for analysis.

Design Line 12. Design line 12 represents three-phase, medium-voltage, ventilated dry-type distribution transformers, ranging from 750 kVA to 2500 kVA. This design line parallels design line 10, with a higher primary insulation level, 46 kV to 95 kV BIL. The typical tap arrangement is four 2½ percent taps, two above and two below the nominal. The primary voltage is typically less than or equal to 15 kV and the secondary voltage is less than or equal to 600 V.

The representative unit selected for this design line is a 1500 kVA transformer, as it is a common rating in this size range and BIL rating, and it occurs in the middle of kVA range covered by this design line (750 kVA, 1000 kVA, 1500 kVA, 2000 kVA, and 2500 kVA).

Design Line 13. As a further extension on the dry-type, three-phase, medium-voltage BIL ranges, the Department analyzed 96 kV to 150 kV BIL, in a design line ranging from 225 kVA to 2500 kVA. The 225 kVA rating is considered to be the lowest kVA rating where one would expect to see a unit with a BIL greater than 110 kV. The typical tap arrangement is four 2½ percent taps, two above and two below the nominal. The primary voltage is typically less than or equal to 35 kV and the secondary voltage is less than or equal to 600 V.

This third set of dry-type, three-phase, medium-voltage distribution transformers spans a smaller range of kVA ratings, 225 kVA to 2500 kVA. As most of the sales activity in this design line occurs in the higher kVA ratings, the representative unit selected for design line 13 is a 2000 kVA transformer. This unit is a common rating in this size range, occurs toward the high end of the range covered by this design line (225 kVA, 300 kVA, 500 kVA, 750 kVA, 1000 kVA, 1500 kVA, 2000 kVA and 2500 kVA). NEMA recommended considering this rating in the Department's analysis. (NEMA, No. 7 at p. 5)

In addition to the three product classes for dry-type, medium-voltage, three-phase distribution transformers (for which there are five engineering design lines) presented in Table 5.2.1, there are three product classes for single-phase, dry-type, medium-voltage units. As discussed in Chapter 3, the shipment volume for the single-phase, dry-type, medium voltage is very low, and thus it does not warrant the level of effort involved in conducting analysis on these specific units. The Department decided instead to scale the analysis findings from three-phase units to the single-phase units by dividing by three. In this way, the Department was able to concentrate resources and improve the accuracy in other, higher volume and more important distribution transformer product classes.

5.2.1 Summary of Design Line Coverage

The following four tables summarize the coverage of each of the design lines in relation to the various product classes and kVA ratings. The abbreviation DL stands for design line, and the row in the table where the phrase "Rep Unit" appears indicates the kVA rating of the representative unit from that design line. For example, DL 1 stands for design line 1, spanning from 10 to 167 kVA liquid-type, single-phase. The label "Rep Unit" appears in row 50 kVA, indicating that the 50 kVA is the representative unit for DL 1. Similarly, the representative unit for DL 2 is the 25 kVA unit.

There are five liquid-immersed design lines, three single-phase and two three-phase, as shown in Table 5.2.3. To capture any design differences between a single-phase pole vs. pad-mounted transformer, the Department analyzed units in both DL 1 and DL 2, spanning the same kVA ratings (10 kVA to 167 kVA). On the three-phase liquid-immersed side, there is no overlap between those two design lines.

Table 5.2.3 Liquid-Immersed Design Lines and Representative Units

Product Class 1 Liquid-Immersed, Single-Phase		
kVA	**Rectang. Tank**	**Round Tank**
10	DL 1	DL 2
15	DL 1	DL 2
25	DL 1	DL 2 Rep Unit
37.5	DL 1	DL 2
50	DL 1 Rep Unit	DL 2
75	DL 1	DL 2
100	DL 1	DL 2
167	DL 1	DL 2
250	DL 3	
333	DL 3	
500	DL 3 Rep Unit	
667	DL 3	
833	DL 3	

Product Class 2 Liquid-Immersed, Three-Phase	
kVA	**Design Lines**
15	DL 4
30	DL 4
45	DL 4
75	DL 4
112.5	DL 4
150	DL 4 Rep Unit
225	DL 4
300	DL 4
500	DL 4
750	DL 5
1000	DL 5
1500	DL 5 Rep Unit
2000	DL 5
2500	DL 5

Table 5.2.4 presents the low-voltage, dry-type design lines. For single-phase units, one design line spans all nine kVA ratings. For the three-phase units, two design lines cover the 11 kVA ratings in that product class. There is no overlap in the design lines for low-voltage dry-type transformers.

Table 5.2.4 Dry-Type, Low-Voltage Design Lines and Representative Units

Product Class 3 Dry-Type, Low-Voltage, Single-Phase		
kVA	**Design Line**	
15	DL 6	
25	DL 6	Rep Unit
37.5	DL 6	
50	DL 6	
75	DL 6	
100	DL 6	
167	DL 6	
250	DL 6	
333	DL 6	

Product Class 4 Dry-Type, Low-Voltage, Three-Phase		
kVA	**Design Line**	
15	DL 7	
30	DL 7	
45	DL 7	
75	DL 7	Rep Unit
112.5	DL 7	
150	DL 7	
225	DL 8	
300	DL 8	Rep Unit
500	DL 8	
750	DL 8	
1000	DL 8	

Table 5.2.5 presents product classes (abbreviated "PC" in this table) for medium-voltage, single-phase, dry-type units. As discussed in section 3.4, National Shipment Estimate, these units have an extremely low shipment volume. All three product classes shown in Table 5.2.5 together represent less than one-third of one percent of dry-type shipments on both a per-unit and an MVA-capacity basis. Thus, the Department did not consider it appropriate to conduct analysis of any units from these three product classes.

As an alternative to investing time and resources analyzing these low-volume units, the Department used the results from the medium voltage three-phase dry-type units (presented in Table 5.2.6) and divided those findings by three, creating virtual (calculated) representative units (labeled as "Virtual RU" in the table) for these three product classes. The Department used the representative units from design lines 9, 10, 11, 12 and 13. These virtual representative units are shown in their respective rows, following the application of the quotient. For example, in the single phase (20–45kV BIL) column, the representative unit from DL 9 is a three-phase 300 kVA unit, so it scales to a single-phase, 100 kVA unit in Table 5.2.5.

Table 5.2.5 Dry-Type, Medium-Voltage, Single-Phase Design Lines

Dry-Type, Medium-Voltage, Single-Phase			
kVA	PC 5* Low BIL 20-45kV	PC 7 Med BIL 46-95kV	PC 9 High BIL ≥96kV
15			-
25			-
37.5			-
50	DL9 / 3	DL11 / 3	-
75			
100	Virtual RU	Virtual RU	
167			
250			
333			DL13 / 3
500	Virtual RU	Virtual RU	
667	DL10 / 3	DL12 / 3	Virtual RU
833			

Table 5.2.6 presents the product classes (abbreviated "PC" in this table) for the medium-voltage, three-phase, dry-type distribution transformers and each of the design lines and respective representative units. For the higher volume and larger range of kVA ratings, the Department used two separate design lines for each, to maintain accuracy. However, for the very high BIL levels (≥96kV BIL), one design line (DL 13) covers all the ratings from 225kVA to 2500kVA. Within DL 13, the Department does not extrapolate the results of this unit to ratings lower than 150kVA because there were no shipments at these ratings in the shipments analysis and it is very unlikely that they would be built.

Table 5.2.6 Dry-Type, Medium-Voltage, Three-Phase Design Lines

Dry-Type, Medium-Voltage, Three-Phase			
kVA	**PC 6 Low BIL 20-45kV**	**PC 8 Med BIL 46-95kV**	**PC 10 High BIL ≥96kV**
15	DL 9	DL 11	-
30	DL 9	DL 11	-
45	DL 9	DL 11	-
75	DL 9	DL 11	-
112.5	DL 9	DL 11	-
150	DL 9	DL 11	-
225	DL 9	DL 11	DL 13
300	DL 9 Rep Unit	DL 11 Rep Unit	DL 13
500	DL 9	DL 11	DL 13
750	DL 10	DL 12	DL 13
1000	DL 10	DL 12	DL 13
1500	DL 10 Rep Unit	DL 12 Rep Unit	DL 13
2000	DL 10	DL 12	DL 13 Rep Unit
2500	DL 10	DL 12	DL 13

5.2.2 Scaling Relationships in Transformer Manufacturing

The Department simplified the engineering analysis by creating design lines, selecting representative units from these design lines, and scaling the results of the analysis on these representative units within their respective design lines. This section briefly introduces the scaling relationship the Department used to extrapolate the findings on the representative units to the other kVA ratings. A more detailed discussion of the derivation of the 0.75 scaling rule is provided in Appendix 5B.

The scaling formulae are mathematical relationships that exist between the kVA ratings and the physical size, cost, and performance of transformers. The size-versus-performance relationships arise from fundamental equations describing a transformer's voltage and kVA rating. For example, when the kVA rating, voltage, and frequency are fixed, the product of the conductor current density, core flux density, core cross-sectional area, and total conductor cross-sectional area is constant.

To illustrate this point, consider a transformer with five fixed variables: frequency, magnetic flux density, current density, and BIL rating. If one enlarges (or decreases) the kVA rating, then the only parameters free to vary are the core cross-section and the core window area through which the windings pass. Thus, to increase (or decrease) the kVA rating, the dimensions for height, width, and depth of the core/coil assembly scale equally in all directions. Analysis of this scaling relationship reveals that each of the linear dimensions varies as the ratio of kVA ratings to the ¼ power. Similarly, areas vary as the ratios of kVA ratings to the ½ power and volumes vary as the ratio of the kVA ratings to the ¾ or 0.75 power, hence the term "0.75 scaling rule." Application of the 0.75

scaling rule assumes that the efficiency profile of a given transformer will have the same shape as the transformer being scaled. Table 5.2.7 depicts the most common scaling relationships in transformers.

Table 5.2.7 Common Scaling Relationships in Transformers

Parameter Being Scaled	Relationship to kVA Rating (varies with ratio of kVA^x)
Weight	$(kVA_1/kVA_0)^{3/4}$
Cost	$(kVA_1/kVA_0)^{3/4}$
Length	$(kVA_1/kVA_0)^{1/4}$
Width	$(kVA_1/kVA_0)^{1/4}$
Height	$(kVA_1/kVA_0)^{1/4}$
Total Losses	$(kVA_1/kVA_0)^{3/4}$
No-load Losses	$(kVA_1/kVA_0)^{3/4}$

The following three relationships are true as the kVA rating increases or decreases, if the type of transformer (liquid-immersed or dry-type, single-phase or three-phase), the primary voltage, the core configuration, the core material, the core flux density, and the current density (amperes per square inch of conductor cross-section) in both the primary and secondary windings are all held constant:

1. The physical proportions are constant (same relative shape),
2. The eddy loss proportion is essentially constant, and
3. The insulation space factor (voltage or BIL) is constant.

In practical applications, it is rare to find that all of the above are constant over even limited ranges; however, over a range of one order of magnitude in both directions (e.g., from 50 kVA to 5 kVA or from 50 kVA to 500 kVA), the scaling rules shown in Table 5.2.7 can be used to establish reasonable estimates of performance, dimensions, costs, and losses. In practice, these rules can be applied over even wider ranges to estimate general performance levels. The Department's application of the 0.75 scaling rule in this analysis is always less than an order of magnitude.

To illustrate how the scaling laws are used, consider two transformers with kVA ratings of S_0 and S_1. The no-load losses (NL) and total losses (TL) of these two transformers would be depicted as NL_0 and TL_0, and NL_1 and TL_1. Then the relationships between the NL and TL of the two transformers could be shown as follows:

$$NL_1 = NL_0 \times (S_1 / S_0)^{0.75} \qquad \textbf{Eq. 5.1}$$

where:

NL_1 = no-load losses of transformer "1,"

NL_0 = no-load losses of transformer "0,"
S_1 = kVA rating of transformer "1," and
S_0 = kVA rating of transformer "0."

and

$$TL_1 = TL_0 \times (S_1 / S_0)^{0.75} \qquad \textbf{Eq. 5.2}$$

where:

TL_1 = total losses of transformer "1," and
TL_0 = total losses of transformer "0."

Equations 5.1 and 5.2 can be manipulated algebraically to show that the load loss also varies to the 0.75 power. Starting with the concept that total losses equals no-load losses plus load losses, we can derive the relationship for load loss (LL), and show that it also scales to the 0.75 power. Specifically:

$$LL_1 = TL_1 - NL_1 \qquad \textbf{Eq. 5.3}$$

where:

LL_1 = load losses of transformer "1"

Inserting the TL_1 and NL_1 terms into this equation, we find:

$$LL_1 = (TL_0 \times (S_1 / S_0)^{0.75}) - (NL_0 \times (S_1 / S_0)^{0.75}) \qquad \textbf{Eq. 5.4}$$

$$LL_1 = (TL_0 - NL_0)\times (S_1 / S_0)^{0.75} \qquad \textbf{Eq. 5.5}$$

$$LL_1 = (LL_0) \times (S_1 / S_0)^{0.75} \qquad \textbf{Eq. 5.6}$$

Where:

LL_0 = load losses of transformer "0."

Thus, the 0.75 scaling rule can be applied to estimate the losses of a transformer, given the losses and kVA rating of a reference (analyzed) unit. However, in order for this rule to be applicable, the transformer type must be the same, and key parameters—such as the type of core material, core flux density, and conductor current density in the high and low voltage windings—must be fixed. Additionally, use of the 0.75 scaling rule assumes that the efficiency profile of a given transformer will have the same shape as the transformer being scaled. Please note that a detailed discussion on the derivation of the 0.75 scaling rule is provided in Appendix 5B.

The Department uses the 0.75 scaling rule to scale the analysis findings on each of the representative units within the 13 design lines to the 102 kVA ratings that were not analyzed. The scaling rule is applied within the design lines in the national impact analysis (Chapter 10), where the Department calculates efficiency ratings for the 102 kVA ratings not analyzed.

5.3 TECHNICAL DESIGN INPUTS

For all thirteen representative units, the engineering analysis explores the relationship between the manufacturer selling prices and corresponding transformer efficiencies. The Department contracted Optimized Program Service (OPS) in Ohio, a software company specializing in transformer design since 1969. Using a range of input parameters and material prices, the OPS software produces a design. This design has specific information about the core and coil, including physical characteristics, dimensions, material requirements and mechanical clearances, as well as a complete electrical analysis of the final design. This optimized, practical transformer design, bill of materials and an electrical analysis report contains sufficient information for a manufacturer to build this unit. The software's output is used to generate an estimated cost of manufacturing materials and labor, which is then converted to a manufacturer selling price by applying markups.

The electrical analysis report estimates the performance of the transformer design (including efficiency) at 25 percent, 35 percent, 50 percent, 65 percent, 75 percent, 100 percent, 125 percent, and 150 percent of nameplate load. The software output provides a clear understanding of the relationship between cost and efficiency because it provides detailed data on design variances, as well as a bill of materials, labor costs, and efficiency. The software does not capture retooling costs associated with changing production designs for a specific manufacturer. In some cases however, the Department captured tooling costs associated with manufacturing mitered cores by applying adders to the steel price.

One of the inputs to the design software consisted of a range of what are known in the industry as A and B evaluation combinations (see section 3.6, Total Ownership Cost Evaluation). The combination of A and B inputted to the design software mimics a distribution transformer purchase order. The A parameter represents a customer's present value of future losses in the transformer core (no-load losses). The B value represents a customer's present value of future losses in the windings (load losses). The B parameter is never larger than A, as this would imply a specification for a transformer whose average load would be more than 100 percent of the nameplate load. The A and B values take into account a range of factors that usually vary from customer to customer.

The A and B values are expressed in terms of dollars per watt of loss. The greater the values of A and B, the greater the importance a customer attaches to the value of future transformer losses. As A and B values increase, the customer places greater importance on reducing the watts of core and winding losses, respectively, and so the customer chooses a more energy efficient transformer.

The Department used broad ranging combinations of A and B evaluation formulae (presented in Table 5.3.1 and Table 5.3.2) to create a complete set of efficiency levels for each design option combination analyzed. The efficiency levels span from a low first-cost unit to a maximum technologically feasible ("max-tech") design. For the low first-cost design, the A and B evaluation values are both $0/watt, indicating that the customer does not attach any financial value to future losses in the core or coil of the transformer. For the maximum technologically feasible design, the A and B evaluation values are very high, pushing the software to design at the highest efficiencies achievable.

The Department created its combinations of A and B evaluation formulae combining two techniques to ensure there were sufficient designs in the database for the analysis. The first technique, as in the ANOPR, the Department created a 'grid' of A and B combinations. The 'grid' technique involves increasing the value of A by a step value, and then increasing the B value from zero to that value of A using a different step value. Thus, if A has incremental steps of $0.25 and B has steps of $0.20, the combinations will work as follows: ($0.00, $0.00), ($0.25, $0.00), ($0.25, $0.20), ($0.50, $0.00), ($0.50, $0.20), ($0.50, $0.40), ($0.75, $0.00), and so on. Table 5.3.1 presents the ranges and incremental steps for the A and B combinations used in the three grids.

Table 5.3.1 A and B Grid Combinations used by Software to Generate Design Database

Grid Number	A values and increments	B values and increments	Resultant # of (A, B) combinations
1	$0 to $2 by 0.25 steps	$0 to $2 by 0.20 steps	47
2	$2.50 to $8 by 0.50 steps	$0 to $8 by 0.40 steps	157
3	$9 to $16 by 1.00 steps	$3 to $8 by 0.50 steps	85

The second technique for generating A and B evaluation formulae in the Engineering Analysis was new for the NOPR. The Department understands that the ratio of A to B represents an implicit loading for the transformer. Therefore, the Department created a set of (A, B) values in which the B is calculated from the A. The B term is calculated as the A times the percent load squared. In other words, if A equals $1 and we are interested in calculating the appropriate B for a 50 percent RMS load, then it would be $1 times (0.50)^2, or $0.25. So the combination of ($1.00, $0.25) represents approximately a 50 percent RMS load. As with the "grid", the A values increased with a step function, and B values were calculated as fractions of A so that the ratio of A to B encompassed the RMS loading points that were identified in the Department's loading analysis (i.e., 35% and 50%). Calling this approach the "fan", the B values were calculated for each A at the following RMS loading points: 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55% and 60%. Table 5.3.2 presents the range of the two fan combinations used in the NOPR.

Table 5.3.2 A and B Fan Combinations used by Software to Generate Design Database

Fan Number	**A values and increments**	**B values and increments**	**Resultant # of (A,B) combinations**
1	$0 to $2 by 0.50 steps	5% to 60% implicit loading by 5% steps	47
2	$3 to $16 by 1.00 steps	5% to 60% implicit loading by 5% steps	182

When used together, these two techniques created a broad spectrum of A and B combinations as inputs to the OPS software. Figure 5.3.1 illustrates the coverage of designs for the 518 A and B combinations.

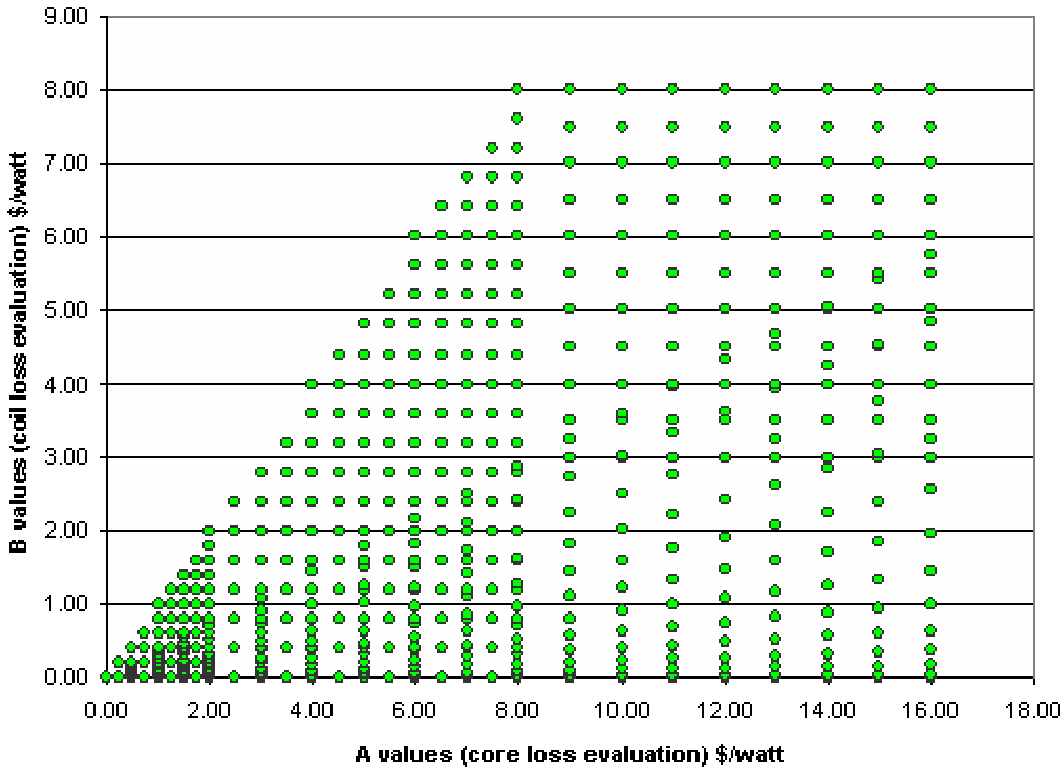

Figure 5.3.1 A and B Combination Software Inputs used in the Engineering Analysis

Occasionally, the design software generated the same transformer design for two different $A and $B combinations, creating duplicate designs in the engineering analysis database. Later, in the LCC analysis, the Department removed any duplicate designs from the engineering database.

The Department understands that there are many ways to build a transformer, even with constant kVA and voltage ratings. For instance, manufacturers can vary the core steels (e.g., M2, M3, M6), the winding materials (aluminum or copper), and core configurations (shell or core-type). Within each of the design lines discussed in the sections starting at 5.3.1, the Department provides tables listing the design option combinations that it used to analyze each of the representative units. Depending on customer needs, the cost of materials, the capital equipment in their facility, and the skills of their labor force, manufacturers make decisions on how to manufacture a given transformer using different core configurations, core steels and winding materials. To capture this variation in designs, DOE analyzed the thirteen representative units using five to eleven different design option combinations of core type, core steel and winding material. As discussed in the technology assessment (see Chapter 3), core steel is produced in a range of qualities (from an efficiency perspective). M2 core steel is grain-oriented and has thin laminations, and consequently has very low losses. M43 core steel is not grain-oriented and is rolled in much thicker laminations, thus contributing to higher core losses. Table 5.3.3 lists all the steel types used in the analysis, and properties associated with these steels, including nominal thickness and core losses per pound of steel. Note that the core losses per pound of steel are given as a function of the magnetic flux density, measured in Tesla.

Table 5.3.3 Core Steel Grades, Thicknesses and Associated Losses

Steel Grade	**Nominal Thickness** *inches*	**Core Loss at 60 Hz** *Watts per Pound at magnetic flux density**	**Notes / Remarks**
M43	0.0185	2.10 Watts/lb at 1.5 T	Non-oriented grain silicon steel
M36	0.0185	2.00 Watts/lb at 1.5 T	Non-oriented grain silicon steel
M19	0.0185	1.65 Watts/lb at 1.5 T	Non-oriented grain silicon steel
M6	0.014	0.66 Watts/lb at 1.5 T 0.94 Watts/lb at 1.7 T	Grain-oriented silicon steel
M5	0.012	0.53 Watts/lb at 1.5 T 0.83 Watts/lb at 1.7 T	Grain-oriented silicon steel
M4	0.011	0.51 Watts/lb at 1.5 T 0.74 Watts/lb at 1.7 T	Grain-oriented silicon steel
M3	0.009	0.45 Watts/lb at 1.5 T 0.70 Watts/lb at 1.7 T	Grain-oriented silicon steel
M2	0.007	0.41 Watts/lb at 1.5 T	Grain-oriented silicon steel
H0	0.009	0.60 Watts/lb at 1.7 T	“High permeability” grade silicon steel
SA1	0.001	0.08 Watts/lb at 1.3 T	Amorphous core steel (silicon and boron); flux density limitation - testing at 1.3 T
ZDMH	0.009	0.34 Watts/lb at 1.5 T 0.46 Watts/lb at 1.7 T	Imported silicon steel, magnetic domain- refined by mechanical process

* Watts of loss per pound of core steel are only comparable at the same magnetic flux density (measured in Tesla)

In addition to selecting a core steel, the manufacturer’s selection of a core design may also contribute to the overall efficiency of a transformer. A transformer facility may be optimized to work around one or two core configurations. Table 5.3.4 provides a list of all the core configurations used for each of the 13 design lines. The Department selected these configurations, in combinations with the range of core steels and winding materials, to represent the most common construction methods for these kVA ratings in the US market. Note that for design lines 2, 3, 6, 7, 8, and 9, the Department analyzed two different core construction configurations.

Table 5.3.4 Core Configurations Used in Each Design Line

Design Line	# Phases	Core Configurations Used in the Engineering Analysis
DL 1	1	Wound core - distributed gap, shell-type
DL 2	1	Wound core - distributed gap, shell-type or core-type
DL 3	1	Wound core - distributed gap, shell-type or core-type
DL 4	3	Wound core - distributed gap, 5-leg
DL 5	3	Wound core - distributed gap, 5-leg
DL 6	1	Stacked, butt-lap, shell-type or core-type
DL 7	3	Stacked, butt-lap or mitered joint, 3-leg
DL 8	3	Stacked, butt-lap or mitered joint, 3-leg
DL 9	3	Stacked, butt-lap or mitered joint, 3-leg
DL 10	3	Stacked, cruciform, mitered joint, 3-leg
DL 11	3	Stacked, mitered joint, 3-leg
DL 12	3	Stacked, cruciform, mitered joint, 3-leg
DL 13	3	Stacked, cruciform, mitered joint, 3-leg

For the single-phase representative units, the configurations used are either core-type or shell-type. This applies whether the core consists of stacked or wound laminations of core steel. For wound cores, manufacturers generally employ a technique known as 'distributed gap.' This means that each lamination of core steel wound around the form will have a start and finish point (the 'gap'), staggered with respect to the laminations on either side. Distributed gap core construction techniques are used to minimize the performance impact of the lamination joint gaps (reducing the exciting current) and, by locating inside the coil window, reduces the transformer's operating sound level. Figure 5.3.2 illustrates the two types of single-phase core configurations.

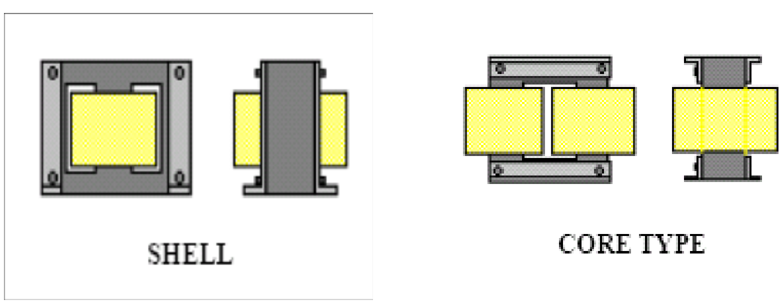

Figure 5.3.2 Graphic of Single-Phase Core Configurations

Three-phase transformers can have three-legged, four-legged, five-legged or Evans cores. Of these, in the engineering analysis, the Department considered the three-legged construction techniques for the three-phase dry-types and five-legged construction for the three-phase liquid-immersed. Figure 5.3.3 below illustrates the difference between the three-legged and the five-legged core construction techniques. A three-legged core is assembled from stacked laminations, the joints of which can be butt-lapped or mitered. Where there is an economic need to reduce core losses, particularly in keeping with the use of more efficient grades of core steel (M2 or M3), the mitered core tends to be selected. The Department recognizes that there are a variety of approaches to mitered core construction - "scrapless T-mitering," "full-mitering," and "step-mitering." The Department modeled the scrapless T and full-mitered cores.

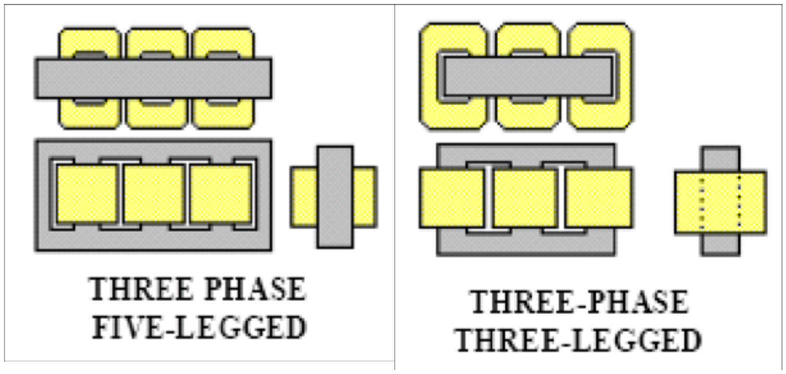

Figure 5.3.3 Graphic of Three-phase Core Configurations

For larger kVA ratings, design economics may cause the selection of a cruciform core section, where multiple lamination widths are stacked in increasing and then decreasing widths to create a circular core form (or "log") around which the windings are placed. Figure 5.3.4 illustrates the cruciform core by showing a cross-section. This figure shows four different widths of steel being used, but there can be fewer or more widths, depending on the design. By using a core configuration that better follows the contours of the windings, losses are again reduced, resulting in a more efficient transformer. The use of the three-legged core usually depends on the primary winding being delta-connected. If the primary winding is wye-connected, as is frequently the case for pad-mounted transformers used in underground distribution, the core configuration needs to be four-legged or five-legged.

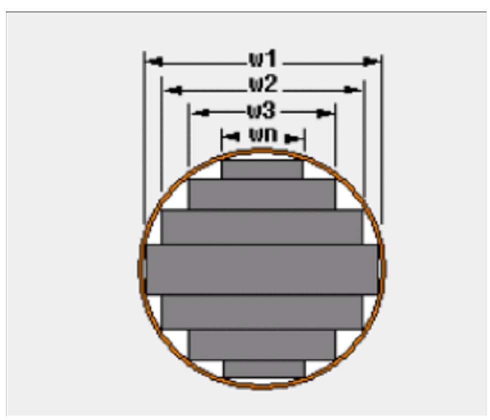

Figure 5.3.4 Cruciform Core Cross-Section

The five-legged core is assembled from four wound-core loops, and is the common configuration for liquid-filled three-phase distribution transformers having a wye-wye voltage connection. Again, this occurs for pad-mounted transformers used in underground distribution. The individual core loops have distributed gaps as explained for single-phase wound-core transformers.

5.3.1 Design Line 1 Representative Unit

Design line 1 (DL 1) represents rectangular-tank, liquid-immersed, single-phase distribution transformers, ranging from 10 kVA to 167 kVA. The representative unit selected for this design line is a 50kVA pad-mounted unit. The following are the technical specifications which constitute input parameters to the OPS design software:

KVA: 50 (liquid-immersed, rectangular-tank)
Primary: 14400 Volts at 60 Hz
Secondary: 240/120V
T Rise: 65˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi-Lo (Shell-Type)
Core: Wound core - distributed gap
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 1.0–3.5 percent

For DL 1, DOE selected eight construction combinations (called "design option combinations"), based on input from manufacturers and other technical experts. The core selected was shell-type, because the application is for a pad-mounted unit, and this shape is well suited to a rectangular tank. With the exception of the max tech/high efficiency designs, DOE selected eight design option combinations to represent the most common construction practices for this representative unit.

Table 5.3.5 Design Option Combinations for the Representative Unit from Design Line 1

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M6	Al (wire)	Al (strip)	Shell - DG Wound Core
M6	Cu (wire)	Al (strip)	Shell - DG Wound Core
M3	Al (wire)	Al (strip)	Shell - DG Wound Core
M3	Cu (wire)	Al (strip)	Shell - DG Wound Core
M2	Cu (wire)	Al (strip)	Shell - DG Wound Core
M2	Cu (wire)	Cu (strip)	Shell - DG Wound Core
ZDMH	Cu (wire)	Cu (strip)	Shell - DG Wound Core
SA1 (Amorphous)	Cu (wire)	Cu (strip)	Shell - DG Wound Core

The Department analyzed each of the eight design option combinations using the matrix of A and B values described in Table 5.3.1, creating 4,144 designs.

5.3.2 Design Line 2 Representative Unit

Design line 2 (DL 2) represents round-tank, liquid-immersed, single-phase distribution transformers, ranging from 10 kVA to 167 kVA. The representative unit selected for this design line is a 25kVA pole-mounted unit. The following are the technical specifications which constitute input parameters to the OPS design software:

KVA: 25 (liquid-immersed, round-tank)
Primary: 14400 Volts at 60 Hz (125 kV BIL)
Secondary: 120/240V
T Rise: 65˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi-Lo (Shell-Type), Lo-Hi (Core-Type, for amorphous core)
Core: Wound core - distributed gap
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 1.0–3.5 percent

For DL 2, DOE selected ten design option combinations, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practices for the representative unit.

Table 5.3.6 Design Option Combinations for the Representative Unit from Design Line 2

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M6	Al (wire)	Al (strip)	Shell - DG Wound Core
M6	Cu (wire)	Al (strip)	Shell - DG Wound Core
M4	Al (wire)	Al (strip)	Shell - DG Wound Core
M4	Cu (wire)	Al (strip)	Shell - DG Wound Core
M3	Cu (wire)	Al (strip)	Shell - DG Wound Core
M3	Cu (wire)	Cu (strip)	Shell - DG Wound Core
M2	Cu (wire)	Al (strip)	Shell - DG Wound Core
M2	Cu (wire)	Cu (strip)	Shell - DG Wound Core
ZDMH	Cu (wire)	Cu (strip)	Shell - DG Wound Core
SA1 (Amorphous)	Cu (wire)	Cu (strip)	Core - DG Wound Core

The Department analyzed each of the ten design option combinations using the matrix of A and B values described in Table 5.3.1, creating 5,180 designs.

5.3.3 Design Line 3 Representative Unit

Design line 3 (DL 3) represents round-tank, liquid-immersed, single-phase distribution transformers, ranging from 250 kVA to 833 kVA. The representative unit selected for this design line is a 500kVA round-tank. The following are the technical specifications which constitute input parameters to the OPS design software:

KVA: 500 (liquid-immersed, round-tank)
Primary: 14400 Volts at 60 HZ (150kV BIL)
Secondary: 277 Volts
T Rise: 65˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi-Lo (Shell-Type), Lo-Hi (Core-Type, for amorphous core)
Core: Wound core - distributed gap
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 2.5–5.75 percent

For DL 3, the Department selected seven design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE chose design option combinations to represent the most common construction practice for this representative unit.

Table 5.3.7 Design Option Combinations for the Representative Unit from Design Line 3

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M6	Al (wire)	Al (strip)	Shell - DG Wound Core
M4	Cu (wire)	Al (strip)	Shell - DG Wound Core
M3	Cu (wire)	Al (strip)	Shell - DG Wound Core
M2	Cu (wire)	Al (strip)	Shell - DG Wound Core
M2	Cu (wire)	Cu (strip)	Shell - DG Wound Core
ZDMH	Cu (wire)	Cu (strip)	Shell - DG Wound Core
SA1 (Amorphous)	Cu (wire)	Cu (strip)	Core- DG Wound Core

The Department analyzed each of the seven design option combinations using the matrix of A and B values described in Table 5.3.1, creating 3,626 designs.

5.3.4 Design Line 4 Representative Unit

Design line 4 (DL 4) represents rectangular tank, liquid-immersed, three-phase distribution transformers, ranging from 15 kVA to 500 kVA. The representative unit selected for this design line is a 150kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 150 (liquid-immersed, pad mount)
Primary: 12470Y/7200 Volts at 60 HZ (95kV BIL)
Secondary: 208Y/120 Volts
T Rise: 65˚C
Ambient: 20˚C
Terminal Configuration: ANSI/IEEE C57.12.26, Loop Feed
Winding Configuration: Lo-Hi (Core-Type)
Core: Wound core - distributed gap, 5-leg
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 1.5–3.0 percent

For DL 4, DOE selected seven design option combinations of core steel and winding types based on input from manufacturers and other technical experts. With the exception of the max tech/high efficiency designs, DOE selected these design option combinations to represent the most common construction practice for the representative unit.

Table 5.3.8 Design Option Combinations for the Representative Unit from Design Line 4

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M6	Al (wire)	Al (strip)	5-Leg DG Core
M4	Al (wire)	Al (strip)	5-Leg DG Core
M3	Cu (wire)	Al (strip)	5-Leg DG Core
M2	Cu (wire)	Al (strip)	5-Leg DG Core
M2	Cu (wire)	Cu (strip)	5-Leg DG Core
ZDMH-price 1	Cu (wire)	Cu (strip)	5-Leg DG Core
SA1 (Amorphous)	Cu (wire)	Cu (strip)	5-Leg DG Core

The Department analyzed each of the seven design option combinations using the matrix of A and B values described in Table 5.3.1, creating 3,626 designs.

5.3.5 Design Line 5 Representative Unit

Design line 5 (DL 5) represents rectangular tank, liquid-immersed, three-phase distribution transformers, ranging from 750 kVA to 2500 kVA. The representative unit selected for this design line is a 1500kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 1500 (liquid-immersed, pad mount)
Primary: 24940GrdY/14400 Volts (125kV BIL)
Secondary: 480Y/277 Volts
T Rise: 65˚C
Ambient: 20˚C

Terminal Configuration: ANSI/IEEE C57.12.26, Loop Feed
Winding Configuration: Lo-Hi (Core-Type)
Core: Wound core - distributed gap, 5-leg
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 4.5-7.0 percent

For DL 5, the Department selected seven design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practices for the representative unit.

Table 5.3.9 Design Option Combinations for the Representative Unit from Design Line 5

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M4	Al (wire)	Al (strip)	5-Leg DG Core
M4	Cu (wire)	Al (strip)	5-Leg DG Core
M3	Cu (wire)	Al (strip)	5-Leg DG Core
M2	Cu (wire)	Al (strip)	5-Leg DG Core
M2	Cu (wire)	Cu (strip)	5-Leg DG Core
ZDMH	Cu (wire)	Cu (strip)	5-Leg DG Core
SA1 (Amorphous)	Cu (wire)	Cu (strip)	5-Leg DG Core

The Department analyzed each of the seven design option combinations using the matrix of A and B values described in Table 5.3.1, creating 3,626 designs.

5.3.6 Design Line 6 Representative Unit

Design line 6 (DL 6) represents ventilated dry-type, single-phase, low-voltage distribution transformers, ranging from 15 kVA to 333 kVA. The representative unit selected for this design line is a 25 kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 25 (dry-type)
Phases: Single
Primary: 480 Volts at 60 Hz (10 kV BIL)
Secondary: 120/240 Volts
T Rise: 150˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi (For Core-Type), Lo-Lo-Hi (For Shell-Type)
Core: Stacked, butt-lap
Taps: Six 2½ percent, two above and four below the nominal
Impedance Range: 3.0–6.0 percent

For DL 6, DOE selected nine design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practice for the representative unit.

Table 5.3.10 Design Option Combinations for the Representative Unit from Design Line 6

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M43, 26 gauge	Al (wire)	Al (wire)	Stacked Core Buttlap
M36, 26 gauge	Al (wire)	Al (wire)	Stacked Core Buttlap
M19, 26 gauge	Al (wire)	Al (wire)	Stacked Core Buttlap
M6	Al (wire)	Al (wire)	Stacked Core Buttlap
M3	Cu (wire)	Al (wire)	Stacked Core Buttlap
H-O DR*	Cu (wire)	Cu (wire)	Stacked Core Buttlap
M6	Al (wire)	Al (wire)	Stacked Shell Buttlap
M3	Cu (wire)	Al (wire)	Stacked Shell Buttlap
H-O DR*	Cu (wire)	Cu (wire)	Stacked Shell Buttlap

* H-O DR is laser-scribed core steel, and represents the max tech for dry-type units.

The Department analyzed each of the nine design option combinations using the matrix of A and B values described in Table 5.3.1, creating 4,662 designs.

5.3.7 Design Line 7 Representative Unit

Design line 7 (DL 7) represents ventilated dry-type, three-phase, low-voltage distribution transformers, ranging from 15 kVA to 150 kVA. The representative unit selected for this design line is a 75 kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 75 (dry-type)
Phases: Three
Primary: 480 Volts at 60 Hz (10 kV BIL)
Secondary: 208Y/120 Volts
T Rise: 150˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi
Core: Stacked, butt-lap; Stacked, mitered
Taps: Six 2½ percent, two above and four below the nominal
Impedance Range: 3.0–6.0 percent

For DL 7, DOE selected eight design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practice for the representative unit.

Table 5.3.11 Design Option Combinations for the Representative Unit from Design Line 7

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M36, 26 gauge	Al (wire)	Al (wire)	3-Leg Stacked Buttlap
M19, 26 gauge	Al (wire)	Al (wire)	3-Leg Stacked Buttlap
M6	Al (wire)	Al (wire)	3-Leg Stacked Buttlap
M6	Al (wire)	Al (wire)	3-Leg Stacked Scrapless T-miter
M6	Al (wire)	Al (wire)	3-Leg Stacked Full Miter**
M4	Cu (wire)	Al (wire)	3-Leg Stacked Full Miter
M3	Cu (wire)	Al (wire)	3-Leg Stacked Full Miter
H-O DR*	Cu (wire)	Cu (wire)	3-Leg Stacked Full Miter

* H-O DR is laser-scribed core steel, and represents the max tech for dry-type units.
** Full Miters are not step-miters, but are mitered joints for all three legs. These cores are stacked three by three.

The Department analyzed each of the seven design option combinations using the matrix of A and B values described in Table 5.3.1, creating 4,144 designs.

5.3.8 Design Line 8 Representative Unit

Design line 8 (DL 8) represents ventilated dry-type, three-phase, low-voltage distribution transformers, ranging from 225 kVA to 1000 kVA. The representative unit selected for this design line is a 300 kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 300 (dry-type)
Phases: Three
Primary: 480V at 60 Hz (10 kV BIL) Delta Connected
Secondary: 208Y/120 Volts
T Rise: 150˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi
Core: Stacked, butt-lap; Stacked, mitered
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 3.0–6.5 percent

For DL 8, the Department selected five design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practice for the representative unit.

Table 5.3.12 Design Option Combinations for the Representative Unit from Design Line 8

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M19, 26 gauge	Al (wire)	Al (wire)	3-Leg Stacked Buttlap
M6, 29 gauge	Al (wire)	Al (strip)	3-Leg Stacked Buttlap
M6, 29 gauge	Cu (wire)	Cu (strip)	3-Leg Stacked Full Miter**
M3	Cu (wire)	Al (strip)	3-Leg Stacked Full Miter
H-O DR*	Cu (wire)	Cu (strip)	3-Leg Stacked Full Miter

* H-O DR is laser-scribed core steel, and represents the max tech for dry-type units.
** Full Miters are not step-miters, but are mitered joints for all three legs. These cores are stacked three by three.

The Department analyzed each of the six design option combinations using the matrix of A and B values described in Table 5.3.1, creating 3,108 designs.

5.3.9 Design Line 9 Representative Unit

Design line 9 (DL 9) represents ventilated dry-type, three-phase, medium-voltage distribution transformers with a 20–45kV BIL, ranging from 15 kVA to 500 kVA. The representative unit selected for this design line is a 300 kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 300 (dry-type)
Phases: Three
Primary: 4160V at 60 Hz (45 kV BIL) Delta Connected
Secondary: 480Y/277 Volts
T Rise: 150˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi
Core: Stacked, butt-lap; Stacked, mitered
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 3.0–6.0 percent

For DL 9, the Department selected five design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practice for the representative unit.

Table 5.3.13 Design Option Combinations for the Representative Unit from Design Line 9

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M6, 29 gauge	Al (wire)	Al (wire)	3-Leg Stacked Buttlap
M6, 29 gauge	Cu (wire)	Cu (wire)	3-Leg Stacked Full Miter**
M5	Al (wire)	Al (wire)	3-Leg Stacked Full Miter
M3	Cu (wire)	Al (strip)	3-Leg Stacked Full Miter
H-O DR*	Cu (wire)	Cu (strip)	3-Leg Stacked Full Miter

* H-O DR is laser-scribed core steel, and represents the max tech for dry-type units.
** Full Miters are not step-miters, but are mitered joints for all three legs. These cores are stacked three by three.

The Department analyzed each of the five design option combinations using the matrix of A and B values described in Table 5.3.1, creating 2,590 designs.

5.3.10 Design Line 10 Representative Unit

Design line 10 (DL 10) represents dry-type, three-phase, medium-voltage distribution transformers with a 20–45kV BIL, ranging from 750 kVA to 2500 kVA. The representative unit selected for this design line is a 1500 kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 1500 (dry-type)
Phases: Three
Primary: 4160V at 60 Hz (45 kV BIL)
Secondary: 480Y/277 Volts
T Rise: 150˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi
Core: Stacked, cruciform, mitered joint
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 4.0-6.0 percent

For DL 10, the Department selected five design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practice for the representative unit.

Table 5.3.14 Design Option Combinations for the Representative Unit from Design Line 10

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M6	Al (wire)	Al (strip)	3-Leg Mitered Cruciform
M6	Cu (wire)	Cu (strip)	3-Leg Mitered Cruciform
M4	Cu (wire)	Al (strip)	3-Leg Mitered Cruciform
M3	Cu (wire)	Cu (strip)	3-Leg Mitered Cruciform
H-O DR*	Cu (wire)	Cu (strip)	3-Leg Mitered Cruciform

* H-O DR is laser-scribed core steel, and represents the max tech for dry-type units.

The Department analyzed each of the five design option combinations using the matrix of A and B values described in Table 5.3.1, creating 2,590 designs.

5.3.11 Design Line 11 Representative Unit

Design line 11 (DL 11) represents dry-type, three-phase, medium-voltage distribution transformers with a 46–95kV BIL, ranging from 15 kVA to 500 kVA. The representative unit selected for this design line is a 300 kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 300 (dry-type)
Phases: Three
Primary: 12470 Volts at 60 Hz (95 kV BIL)
Secondary: 480Y/277 Volts
T Rise: 150˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi
Core: Stacked, mitered joint
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 3.0-7.0 percent

For DL 11, the Department selected five design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practice for the representative unit.

Table 5.3.15 Design Option Combinations for the Representative Unit from Design Line 11

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M6	Al (wire)	Al (strip)	3-Leg Stacked Full Miter**
M6	Cu (wire)	Cu (strip)	3-Leg Stacked Full Miter
M4	Cu (wire)	Al (strip)	3-Leg Stacked Full Miter
M3	Cu (wire)	Cu (strip)	3-Leg Stacked Full Miter
H-O DR*	Cu (wire)	Cu (strip)	3-Leg Stacked Full Miter

* H-O DR is laser-scribed core steel, and represents the max tech for dry-type units.
** Full Miters are not step-miters, but are mitered joints for all three legs. These cores are stacked three by three.

The Department analyzed each of the five design option combinations using the matrix of A and B values described in Table 5.3.1, creating 2,590 designs.

5.3.12 Design Line 12 Representative Unit

Design line 12 (DL 12) represents dry-type, three-phase, medium-voltage distribution transformers with a 46–95kV BIL, ranging from 750 kVA to 2500 kVA. The representative unit selected for this design line is a 1500 kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 1500 (dry-type)
Phases: Three
Primary: 12470 Volts at 60 Hz (95 kV BIL)
Secondary: 480Y/277 Volts
T Rise: 150˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi
Core: Stacked, cruciform, mitered joint
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 4.0–7.0 percent

For DL 12, the Department selected five design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practice for the representative unit.

Table 5.3.16 Design Option Combinations for the Representative Unit from Design Line 12

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M6	Al (wire)	Al (strip)	3-Leg Mitered Cruciform
M6	Cu (wire)	Cu (strip)	3-Leg Mitered Cruciform
M4	Cu (wire)	Al (strip)	3-Leg Mitered Cruciform
M3	Cu (wire)	Cu (strip)	3-Leg Mitered Cruciform
H-O DR*	Cu (wire)	Cu (strip)	3-Leg Mitered Cruciform

* H-O DR is laser-scribed core steel, and represents the max tech for dry-type units.

The Department analyzed each of the five design option combinations using the matrix of A and B values described in Table 5.3.1, creating 2,590 designs.

5.3.13 Design Line 13 Representative Unit

Design line 13 (DL 13) represents dry-type, three-phase, medium-voltage distribution transformers with a ≥96kV BIL, ranging from 225 kVA to 2500 kVA. The representative unit selected for this design line is a 2000 kVA transformer. The following are the technical specifications that constitute input parameters to the OPS design software:

KVA: 2000 (dry-type)
Phases: Three
Primary: 12470 Volts at 60 Hz (125 kV BIL)
Secondary: 480Y/277 Volts
T Rise: 150˚C
Ambient: 20˚C
Winding Configuration: Lo-Hi
Core: Stacked, cruciform, mitered joint
Taps: Four 2½ percent, two above and two below the nominal
Impedance Range: 4.0–7.0 percent

For DL 13, the Department selected five design option combinations of core steel and winding material, based on input from manufacturers and other technical experts. With the exception of the max tech/high-efficiency designs, DOE selected these design option combinations to represent the most common construction practice for the representative unit.

Table 5.3.17 Design Option Combinations for the Representative Unit from Design Line 13

Core Material	High Voltage Conductor	Low Voltage Conductor	Core Design Type
M6	Al (wire)	Al (strip)	3-Leg Mitered Cruciform
M6	Cu (wire)	Cu (strip)	3-Leg Mitered Cruciform
M4	Cu (wire)	Al (strip)	3-Leg Mitered Cruciform
M3	Cu (wire)	Cu (strip)	3-Leg Mitered Cruciform
H-O DR*	Cu (wire)	Cu (strip)	3-Leg Mitered Cruciform

* H-O DR is laser-scribed core steel, and represents the max tech for dry-type units.

The Department analyzed each of the five design option combinations using the matrix of A and B values described in Table 5.3.1, creating 2,590 designs.

5.4 MATERIAL AND LABOR INPUTS

The Department uses a standard method of cost accounting to determine the costs associated with manufacturing. This methodology is illustrated in Figure 5.4.1, where production costs and non-production costs are combined to determine the manufacturer's selling price of a product.

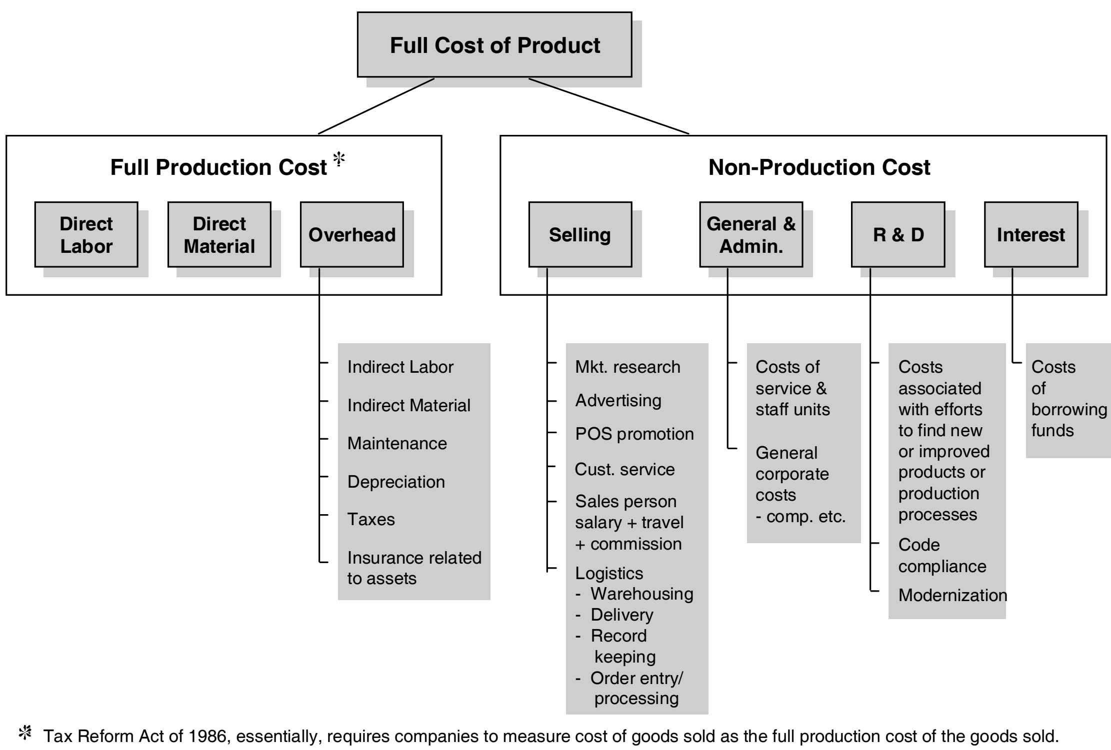

Figure 5.4.1 Standard Method of Cost Accounting for Standards Rulemaking

The full production cost and the non-production cost equal the manufacturer's selling price of the product. Full production cost is a combination of direct labor, direct materials, and overhead. The overhead contributing to full production cost includes indirect labor, indirect material, maintenance, depreciation, taxes, and insurance related to company assets. Non-production cost includes the cost of selling (market research, advertising, sales representatives, logistics), general and administrative costs, research and development, interest payments and profit factor (not shown). Because profit factor is included in the non-production cost, the sum of production and non-production costs is an estimate of the manufacturer's selling price.

The Department developed estimates of the costs listed in Figure 5.4.1 from the U.S. *Industry Census Data Reports* for 1992 and 1997, manufacturer interviews, and SEC 10-K reports for ACME Electric Corporation, Powell Industries, Inc., Magnetek, Inc., and Hammond Manufacturing Company Limited. These estimates were then refined through meetings and dialogue with transformer manufacturers in early 2002. The following markups resulted:

- Scrap and handling factor: 2.5 percent markup. This markup applies to variable materials (e.g., core steel, windings, insulation). It accounts for the handling of material (loading into assembly or winding equipment) and the scrap material that cannot be used in the production of a finished transformer (e.g., lengths of wire too short to wind, trimmed core steel).

- Mitered scrap factor: 4.0 percent markup. An additional scrap markup applies to steel used in full-mitered cores. This markup represents material cut from the notch in the yoke.

- Factory overhead: 12.5 percent markup. Factory overhead includes all the indirect costs associated with production, indirect materials and energy use (e.g., annealing furnace), taxes, and insurance. The Department only applies factory overhead to the direct material production costs.

- Non-production: 25 percent markup. This markup reflects costs including selling, general and administrative, R&D, interest payments, and profit factor. The Department applies the non-production markup to the sum of direct material, direct labor, and factory overhead.

The following example shows how the Department applied the markups to the materials, and how it determined the manufacturer selling price. Consider a 300kVA 45kV BIL three-phase dry-type transformer designed for a $1.50 A and a $0.60 B. This design has $3,048 of materials, including M6 core steel, copper primary and secondary windings, and all the transformer hardware. There are approximately 26 hours of labor involved in manufacturing this design, resulting in a labor cost of $1,147. The factory overhead on this design is $381, as it is only applied to the material cost (i.e., 12.5 percent of $3,048). The non-production cost is $1,144, as the 25 percent is applied to the material, labor, and factory overhead costs (i.e., 25 percent of $3,048 + $1,147 + $381). Thus, in total, DOE estimates this 300kVA three-phase transformer to have a manufacturer selling price of $5,720.

5.4.1 Material Prices

The Department received considerable input from manufacturers concerning recent increases in the cost of materials, particularly core steel. The Department uses prices of core steel, conductor, mineral oil, insulation and other materials as an input to the transformer design software used for the engineering analysis. As the price of one material increases or decreases relative to the other materials, the software will modify its design and increase or decrease the amount of that material while balancing other design parameters, creating a cost-optimized transformer. Material pricing is also critical because the manufacturer's selling prices calculated in the engineering analysis are based on a bill of materials that includes specifications for pounds of steel, pounds of conductor, gallons of mineral oil, tank dimensions and so on. Therefore, as material prices increase, so will the manufacturer's selling price. Furthermore, as discussed in Chapter 3, energy-efficient transformers tend to incorporate more materials (e.g., pounds of core steel, pounds of conductor), making the impact of more expensive materials even more significant at higher efficiencies.

The Department contracted Optimized Program Service (OPS) to develop material price estimates for the engineering analysis. OPS used data from their own records as well as data provided by transformer manufacturers and material suppliers and wholesalers. The resulting prices are intended to be representative of a standard quantity order for a medium- to large-scale U.S. transformer manufacturer. The Department conducted the engineering analysis using two material price scenarios - 1) a five-year average of the material prices (in constant 2004 dollars) from 2000, 2001, 2002, 2003, and 2004 and 2) a more recent material price sensitivity, using material prices from the first quarter of 2005. The consideration of a second set of material prices in the engineering analysis was directly in response to comments received during the review of the ANOPR analysis that material prices are increasing rapidly and the historical lows of recent past were unlikely to be experienced again. The results of the first quarter 2005 engineering analysis are presented in Appendix 5C.

The Department noted that the most critical material input to a distribution transformer, electrical core steel, had increased by more than 100% for some M-grades between the five-year average price and the first quarter of 2005 (see Table 5.4.1 on the next page). For this reason, the Department researched the grain-oriented electrical steel market to gain a better understanding of the main players and some of the factors influencing this significant price increase (see Appendix 3A).

In the life-cycle cost (LCC) analysis (see Chapter 8), the Department presents results on its sensitivity analyses conducted on various LCC inputs, which includes material prices. In Chapter 8, the Q1 2005 material price is referred to as the "high" price scenario and the 2000-2004 average price scenario is called the "medium" price scenario. The Department then developed a hypothetical "low" price scenario in order to establish a lower bound for the LCC sensitivity analysis. The low price scenario is based on material prices in 2002 (the calender year with the lowest $/pound for M6 core steel) and reduces all the material prices in that year by 15%. These material prices can be found in the material price tables presented in this section. The resulting low-price scenario manufacturer selling prices are provided in the LCC spreadsheets

5.4.2 Material Inputs to the Design Software - Liquid-Immersed

Table 5.4.1 presents the material prices for a typical liquid-immersed transformer manufacturer in the first quarter 2005, the hypothetical low material prices (for the LCC material price sensitivity, presented in Chapter 8) and the 2000-2004 five-year average prices (all in constant 2004 dollars). The highlighted columns are the prices that were used in the engineering analysis.

Table 5.4.1 Manufacturer's Material Prices for Liquid-Immersed Design Lines

Material	**Q1 2005** *$/lb.*	**2002 -15%** *2004$/lb.*	**5-Year Average** *2004$/lb.*	**2004** *2004$/lb.*	**2003** *2004$/lb.*	**2002** *2004$/lb.*	**2001** *2004$/lb.*	**2000** *2004$/lb.*
M2 core steel	1.71	0.76	0.95	0.95	0.88	0.89	1.00	1.04
M3 core steel	1.63	0.65	0.80	0.80	0.78	0.76	0.82	0.86
M4 core steel	1.56	0.64	0.76	0.75	0.72	0.75	0.79	0.81
M6 core steel	1.42	0.57	0.70	0.69	0.69	0.67	0.72	0.74
ZDMH (mechanically-scribed core steel)	2.75	1.23	1.47	1.50	1.42	1.45	1.47	1.51
SA1 (amorphous) - finished core, volume production	2.50	1.51	1.80	1.89	1.78	1.78	1.79	1.78
Copper wire, formvar, round #10-20	2.25	1.11	1.55	2.10	1.48	1.31	1.37	1.47
Copper wire, enameled, round #7-10 flattened	2.21	1.09	1.51	2.05	1.45	1.28	1.34	1.42
Copper wire, enameled, rectangular sizes	2.65	1.18	1.76	2.51	2.02	1.39	1.46	1.42
Aluminum wire, formvar, round #9-17	1.56	1.15	1.43	1.53	1.41	1.35	1.43	1.45
Aluminum wire, formvar, round #7-10	1.58	1.16	1.46	1.54	1.43	1.36	1.45	1.50
Copper strip, thickness range 0.020-0.045	2.92	1.86	2.32	2.50	2.24	2.19	2.31	2.35
Copper strip, thickness range 0.030-0.060	2.84	1.79	2.24	2.44	2.15	2.11	2.23	2.27
Aluminum strip, thickness range 0.020-0.045	1.66	1.30	1.54	1.60	1.58	1.53	1.47	1.53
Aluminum strip, thickness range 0.045-0.080	1.69	1.24	1.45	1.51	1.49	1.46	1.39	1.42
Kraft insulating paper with diamond adhesive	1.56	1.32	1.59	1.56	1.54	1.55	1.62	1.66
Tank steel	0.50	0.29	0.35	0.35	0.33	0.34	0.37	0.38
Mineral oil	2.40	1.45	1.71	1.80	1.73	1.71	1.60	1.72

The raw material prices presented in Table 5.4.1 are then marked-up using the manufacturer's internal mark-ups discussed in section 5.4. For example, a raw material price of $1.00/lb. would be marked-up to $1.44/lb., reflecting the handling and scrap factor (2.5 percent), the factory overhead (12.5 percent), and the non-production markup (25 percent). The marked-up material prices are then used as inputs to the transformer design software. During the manufacturer site visits in early 2002, the Department found this approach to be consistent with that of several manufacturers who operate their own, proprietary transformer design software. Table 5.4.2 shows the mark-up steps being applied to the 5-year average material price scenario (2000-2004).

Table 5.4.2 Marked-up Material Prices for Liquid-Immersed Units, 5-year Average Price Scenario

Item and Description	Material Price*	Scrap & Handling	Factory Overhead	Non-Production	Software Input
M2 core steel	$0.95	1.025	1.125	1.25	$1.37
M3 core steel	$0.80	1.025	1.125	1.25	$1.17
M4 core steel	$0.76	1.025	1.125	1.25	$1.10
M6 core steel	$0.70	1.025	1.125	1.25	$1.01
ZDMH (mechanically-scribed core steel, finished core)	$1.47 + 0.30	1.015	1.125	1.25	$2.53
SA1 (amorphous material) - finished core, volume production	$1.80 + 0.30	1.015	1.125	1.25	$3.00
Copper wire, formvar, round #10-20 (DL 1,2,4)	$1.55	1.025	1.125	1.25	$2.23
Copper wire, enameled, round #7-10 flattened (DL 3,5)	$1.51	1.025	1.125	1.25	$2.18
Copper wire, enameled, rectangular sizes (DL 3)	$1.76	1.025	1.125	1.25	$2.54
Aluminum wire, formvar, round #9-17 (DL 1,2,4)	$1.43	1.025	1.125	1.25	$2.08
Aluminum wire, formvar, round #7-10 (DL 3,5)	$1.46	1.025	1.125	1.25	$2.10
Copper strip, thickness range 0.02-0.045 (DL 1,2,4)	$2.32	1.025	1.125	1.25	$3.34
Copper strip, thickness range 0.030-0.060 (DL 3,5)	$2.24	1.025	1.125	1.25	$3.23
Aluminum strip, thickness range 0.02-0.045 (DL 1,2,4)	$1.54	1.025	1.125	1.25	$2.22
Aluminum strip, thickness range 0.045-0.080 (DL 3,5)	$1.45	1.025	1.125	1.25	$2.09
Kraft insulating paper with diamond adhesive	$1.59	1.025	1.125	1.25	$2.29
Tank Steel	$0.35	1.025	1.125	1.25	$0.50
Mineral oil (per gallon)	$1.71	-	1.125	1.25	$2.40

* Five year average (2000 through 2004) for materials expressed in 2004$ per lb. ZDMH and SA1 include $0.30/lb adder for finished core.

Several manufacturers commented to the Department that the U.S. has a 31% anti-dumping import duty on core steel produced in Japan. One of the core steels considered by the Department as a high-efficiency grade steel for the liquid-immersed wound-core units was ZDMH. ZDMH is a mechanically scribed, grain-oriented electrical steel. The process for manufacturing this steel is patented, and it is only produced in Japan. For the Advance Notice of Proposed Rulemaking (ANOPR) analysis, the Department considered two price points for ZDMH, one reflecting what a U.S. manufacturer would pay with the import duty and the other reflecting what a manufacturer in Mexico or Canada would pay (no duty). The duty only applies to ZDMH raw material, it does not apply to the material if 'substantial rework' were done prior to importation (e.g., building a transformer or a core outside the U.S. and then importing it). The Department is concerned that if ZDMH offered a more cost-effective set of liquid-immersed designs for standards compliance, it may give manufacturers outside the U.S. a competitive advantage over domestic manufacturers.

For the NOPR analysis, the Department modified its use of ZDMH pricing in the engineering analysis due to input received from several manufacturers. These companies indicated to the Department that if ZDMH offered the most cost-effective liquid-immersed designs, then they would out-source core fabrication to a Mexican or Canadian company and import finished cores. Finished ZDMH cores are not subject to the importation duty, thus the ZDMH price did not include the 31% import duty, but did include an adder for core processing. The MIA (see Chapter 12) discusses the effect of this scenario on U.S. transformer manufacturer employment.

In addition to the aforementioned materials that vary during the design optimization process (e.g., core steel, windings, insulation, etc.), there are other direct materials inputs that are fixed costs and generally do not influence the design or vary with efficiency rating. These include direct materials such as the high- and low-voltage bushings and the core clamps. Estimates of the tank fabrication cost are also prepared, based on the optimized transformer design (the software considers this variable) and the labor necessary to build the tank. Table 5.4.2, on the next page, summarizes all the estimated fixed material costs and estimates of the tank costs for each of the five liquid-immersed design lines.

For design line 1, a 50kVA single-phase pad-mounted unit, the high-voltage bushings are two universal bushing wells, 15 kV, 95 BIL, 14400V, costing $7 each. The low-voltage bushings are three threaded copper studs, 240/120V, 50 kVA, costing $20 for the set. Internal hardware costs includes a core clamp, nameplate, and other miscellaneous hardware costing $25.65. The finished tank size (and associated cost) varies by design, but the average is approximately $130.

For design line 2, a 25kVA single-phase pole-mounted unit, the high-voltage terminal is a single wet-process porcelain bushing assembly, 15 kV, 125 BIL, costing $6.00. The low-voltage terminals are three molded polymer bushings, 120/240V, 25 kVA, costing $8.00 for the set. Internal hardware costs include a core clamp, nameplate, and other miscellaneous hardware, costing $19.15. The finished tank sizes (height and diameter) vary by design, but the average is approximately $70.

For design line 3, a 500kVA single-phase unit, the high-voltage connector is a single wet-process porcelain bushing, 25 kV, 125 BIL, costing $6.00. The low-voltage bushings are two four-hole "J" Spade 500kVA, 277V, costing $60 for the set. The internal hardware includes a core clamp ($30), nameplate ($0.65) and miscellaneous hardware ($20), totaling $50.65. The design software optimized the tank cost with each design, including radiators (external cooling) for this kVA rating.

The resultant finished round tank has a diameter of 33" to 52", with an average cost of approximately $500 (including radiators).

For design line 4, a 150kVA three-phase, pad-mounted unit, the high-voltage bushings are three externally clamped universal high-voltage bushing wells, 8.3/14.4 kV, 95 BIL, costing $7 each. The low-voltage bushings are three copper studs at $8 each. The internal hardware includes core clamps ($30), nameplate ($0.65) and miscellaneous hardware ($45), totaling $75.65 The optimized finished tank sizes measure 50 inches high and vary in width and depth. The finished rectangular, welded tank has an average cost of approximately $360.

For design line 5, a 1500kVA three-phase, pad-mounted unit, the high-voltage bushings are three externally clamped universal high-voltage bushing wells, 15.2/26.3 kV, 125kV BIL, costing $20 each. The low-voltage bushings are four externally clamped bushings, each having six-hole spade, costing $160 for the set. The internal hardware includes core clamps ($60), nameplate ($0.65) and miscellaneous hardware ($45), totaling $105.65. The optimized finished tank sizes measure 70 inches high and vary in width and depth. The finished rectangular, welded tank, including radiators as specified by the design software, has an average cost of approximately $800.

Table 5.4.3 Summary Table of Fixed Material Costs for Liquid-Immersed Units

Item	DL 1	DL 2	DL 3	DL 4	DL 5
High voltage bushings	$14	$6	$6	$21	$60
Low voltage bushings	$20	$8	$60	$24	$160
Core clamp, nameplate, and misc. hardware	$25.65	$19.15	$50.65	$75.65	$105.65
Transformer tank average cost*	$130	$70	$500	$360	$800

* Transformer tank steel is used in the design optimization software and varies with the efficiency (and size) of each design. DL3 and DL5 include calculated costs of radiators, which are scaled for each design based on the required cooling surface area.

5.4.3 Material Inputs to the Design Software - Dry-type

Table 5.4.3 presents the material prices for a typical dry-type transformer manufacturer in the first quarter 2005, the hypothetical low material prices (for the LCC material price sensitivity, presented in Chapter 8) and the 2000-2004 five-year average prices (all in constant 2004 dollars). The highlighted columns are the prices used in the engineering analysis.

Table 5.4.4 Manufacturer's Material Prices for Dry-Type Design Lines

Material	Q1 2005 *$/lb.*	2002 -15% *2004$/lb.*	5-Year Average *2004$/lb.*	2004 *2004$/lb.*	2003 *2004$/lb.*	2002 *2004$/lb.*	2001 *2004$/lb.*	2000 *2004$/lb.*
H-O DR core steel (laser-scribed)	1.85	0.82	0.99	1.00	0.92	0.97	1.01	1.04
M3 core steel	1.63	0.65	0.80	0.80	0.78	0.76	0.82	0.86
M4 core steel	1.56	0.64	0.76	0.75	0.72	0.75	0.79	0.81
M5 core steel	1.47	0.60	0.72	0.73	0.63	0.70	0.77	0.77
M6 core steel	1.42	0.57	0.70	0.69	0.69	0.67	0.72	0.74
M19 core steel (26 gauge)	0.82	0.43	0.56	0.55	0.52	0.51	0.59	0.62
M36 core steel (29 gauge)	0.69	0.42	0.50	0.53	0.49	0.49	0.48	0.51
M36 core steel (26 gauge)	0.65	0.36	0.45	0.51	0.44	0.42	0.44	0.46
M43 core steel (26 gauge)	0.58	0.36	0.43	0.48	0.43	0.42	0.41	0.43
Copper wire, rectangular 0.1 x 0.2, Nomex wrap	2.69	1.39	2.00	2.72	2.24	1.63	1.68	1.74
Aluminum wire, rectangular 0.1 x 0.2, Nomex wrap	2.05	1.71	2.06	2.04	2.01	2.01	2.10	2.13
Copper strip, thickness range 0.020-0.045	2.92	1.86	2.32	2.50	2.24	2.19	2.31	2.35
Aluminum strip, thickness range 0.020-0.045	1.66	1.30	1.54	1.60	1.58	1.53	1.47	1.53
Nomex insulation (per pound)	18.00	15.38	18.11	18.00	17.76	18.09	18.39	18.29
Cequin insulation (per pound)	12.00	10.54	11.99	12.00	12.18	12.40	11.56	11.83
Impregnation (per gallon)	19.00	14.93	17.80	18.00	17.26	17.57	17.86	18.29
Enclosure Steel (per pound)	0.50	0.29	0.35	0.35	0.33	0.34	0.37	0.38
Winding combs (per pound)	10.00	8.79	10.24	10.00	10.15	10.34	10.51	10.22

On the following pages, all the material prices entered into the design software for dry-type distribution transformers are given. As shown in these tables, the Department marked up the material prices before being entering them into the design software.

Table 5.4.5 Marked-up Material Prices for Dry-Type Units, 5-year Average Price Scenario

Item and Description	Material Price*	Scrap & Handling	Factory Overhead	Non-Production	Software Input
H-O DR core steel (laser-scribed)	$0.99	1.025	1.125	1.25	$1.43
M3 core steel	$0.80	1.025	1.125	1.25	$1.17
M4 core steel	$0.76	1.025	1.125	1.25	$1.10
M5 core steel	$0.72	1.025	1.125	1.25	$1.04
M6 core steel	$0.70	1.025	1.125	1.25	$1.01
M19 core steel (26 gauge)	$0.56	1.025	1.125	1.25	$0.81
M36 core steel (29 gauge)	$0.50	1.025	1.125	1.25	$0.72
M36 core steel (26 gauge)	$0.45	1.025	1.125	1.25	$0.65
M43 core steel (26 gauge)	$0.43	1.025	1.125	1.25	$0.62
Copper wire, rectangular 0.1 x 0.2, Nomex wrapped	$2.00	1.025	1.125	1.25	$2.88
Aluminum wire, rectangular 0.1 x 0.2, Nomex wrapped	$2.06	1.025	1.125	1.25	$2.97
Copper strip, thickness range .02-.045	$2.32	1.025	1.125	1.25	$3.34
Aluminum strip, thickness range .02-.045	$1.54	1.025	1.125	1.25	$2.22
Nomex insulation (per pound)	$18.11	1.025	1.125	1.25	$26.10
Cequin insulation (per pound)	$11.99	1.025	1.125	1.25	$17.30
Impregnation (per gallon)	$17.80	-	1.125	1.25	$25.03
Enclosure steel (per pound)	$0.35	1.025	1.125	1.25	$0.50
Winding Combs (per pound)	$10.24	1.025	1.125	1.25	$14.76

* Five year average (2000 through 2004) for materials expressed in 2004$ per lb. Average compiled by Paul Goethe, Optimized Program Service, January 2005.

As stated in section 5.3, the OPS software does not take into account retooling costs associated with changing production designs. Therefore, to partially capture these differential costs in design lines that had both buttlap and mitered designs, the Department used adders in design lines 7, 8, and 9. The adders specified an extra ten cents per pound of core steel for full-mitered designs and an extra five cents per pound of core steel for T-mitered designs. More detailed costing of the retooling costs for mitering equipment is captured in the manufacturer impact analysis (see Chapter 12).

Similar to the liquid-immersed designs, there are fixed (and some partially variable) hardware costs associated with dry-type distribution transformers. These are discussed individually and then summarized in Table 5.4.6.

For design line 6, a 25 kVA single-phase, low-voltage, dry-type, the fixed hardware costs are $4 for the low-voltage and high-voltage terminals. The mounting frame for attaching the core/coil assembly to the transformer enclosure is estimated as $9.25. The fiberglass dog-bone duct-spacers used for this design line cost $0.24 per foot. The miscellaneous hardware costs were estimated to be $4.50. The ventilated enclosure, a 14-gauge steel enclosure, base, and mounting feet varies with the size of the core-coil assembly, however it costs approximately $65.

For design line 7, a 75 kVA three-phase, low-voltage, dry-type, the fixed hardware costs are $9 for the high-voltage terminal board with connection points. The low voltage bus-bar is estimated to be seven feet at $1.50 per foot, or $10.50. The mounting frame that attaches the core/coil assembly to the transformer enclosure is estimated to cost $19. The fiberglass dog-bone duct-spacers used for this design line are $0.32 per foot. The miscellaneous hardware costs were estimated at $7. The ventilated enclosure, a 14-gauge steel enclosure, base, and mounting feet varies with the size of the core-coil assembly, however it costs approximately $70.

For design line 8, a 300 kVA three-phase, low-voltage, dry-type, the high-voltage terminal boards cost $27. The low-voltage bus-bar is estimated to be nine feet at $2.50 per foot, or $22.50. The mounting frame that attaches the core/coil assembly to the transformer enclosure costs approximately $36. The fiberglass dog-bone duct-spacers used for this design line cost $0.42 per foot. The miscellaneous hardware costs were estimated at $12. The ventilated enclosure, a 14-gauge steel enclosure, base, and mounting feet varies with the size of the core-coil assembly, however it costs approximately $175.

For design line 9, a 300 kVA three-phase medium-voltage dry-type at 45 kV BIL, the low-voltage and high-voltage terminal set costs $75. The low-voltage bus-bar is estimated to be eight feet at $10 per foot, or $80. The mounting frame that attaches the core/coil assembly to the transformer enclosure costs approximately $36. The fiberglass dog-bone duct-spacers used for this design line cost $0.42 per foot. The miscellaneous hardware costs were estimated at $25. The ventilated enclosure, a 14-gauge steel enclosure, base, and mounting feet varies with the size of the core-coil assembly, however it costs approximately $175.

For design line 10, a 1500 kVA three-phase medium-voltage dry-type at 45 kV BIL, the low-voltage and high-voltage terminal set costs $120. The low voltage bus-bar is estimated to be fourteen feet at $10 per foot, or $140. The mounting frame that attaches the core/coil assembly to the transformer enclosure costs approximately $120. The fiberglass dog-bone duct-spacers used for this design line cost $0.52 per foot. The miscellaneous hardware costs were estimated at $42. The ventilated enclosure, a 12-gauge steel enclosure, base, and mounting feet varies with the size of the core-coil assembly, however it costs approximately $600.

For design line 11, a 300 kVA three-phase medium-voltage dry-type at 95 kV BIL, the low-voltage and high-voltage terminal set costs $100. The high-voltage terminal boards cost $27. The low-voltage bus-bar is estimated to be ten feet at $8 per foot, or $80. The mounting frame that attaches the core/coil assembly to the transformer enclosure costs $42. The fiberglass dog-bone duct-spacers used for this design line cost $0.42 per foot. The miscellaneous hardware costs were estimated at $32. The ventilated enclosure, a 14-gauge steel enclosure, base, and mounting feet varies with the size of the core-coil assembly, however it costs approximately $300.

For design line 12, a 1500 kVA three-phase medium-voltage dry-type at 95 kV BIL, the low-voltage and high-voltage terminal set costs $135. The high-voltage terminal boards cost $27. The low-voltage bus-bar is estimated to be sixteen feet at $12 per foot, or $192. The mounting frame that attaches the core/coil assembly to the transformer enclosure costs $125. The fiberglass dog-bone duct-spacers used for this design line cost $0.56 per foot. The miscellaneous hardware costs were estimated at $54. The ventilated enclosure, a 12-gauge steel enclosure, base, and mounting feet varies with the size of the core-coil assembly, however it costs approximately $770.

For design line 13, a 2000 kVA three-phase medium-voltage dry-type at 125 kV BIL, the low-voltage and high-voltage terminal set costs $150. The high-voltage terminal boards cost $27. The low-voltage bus-bar is estimated to be eighteen feet at $15 per foot, or $270. The mounting frame that attaches the core/coil assembly to the transformer enclosure costs $175. The fiberglass dog-bone duct-spacers used for this design line cost $0.60 per foot. The miscellaneous hardware costs were estimated at $60. The ventilated enclosure, a 12-gauge steel enclosure, base, and mounting feet varies with the size of the core-coil assembly, however it costs approximately $835.

Table 5.4.6 Summary Table of Fixed Material Costs for Dry-Type Units

Item	**DL 6**	**DL 7**	**DL 8**	**DL 9**	**DL 10**	**DL 11**	**DL 12**	**DL 13**
LV and HV terminals (set)	$4	n/a	n/a	$75	$120	$100	$135	$150
HV terminal board(s)	n/a	$27	$27	$27	$27	$27	$27	$27
LV bus-bar	n/a	$10.50	$22.50	$80	$140	$80	$192	$270
Core/coil mounting frame	$9.25	$19	$36	$36	$120	$42	$125	$175
Nameplate	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65
Dog-bone duct-spacer (ft.)	$0.24	$0.32	$0.42	$0.42	$0.52	$0.42	$0.56	$0.60
Winding combs (lb.)	n/a	n/a	n/a	n/a	n/a	$10.24	$10.24	$10.24
Misc. hardware	$4.50	$7	$12	$25	$42	$32	$54	$60
Enclosure (12, 14 gauge)	~$65	~$125	~$175	~$250	~$600	~$300	~$770	~$835

5.4.4 Labor Costs

Labor costs constitute a critical aspect of the cost of manufacturing a distribution transformer. The Department used the same hourly labor cost for both liquid and dry-type distribution transformers. The Department developed the hourly cost of labor using a similar approach to the development of the cost of materials; however, it used different markups with the exception of the non-production markup. The Department developed the markups shown in Table 5.4.7 after reviewing publicly available information and consulting with industry experts familiar with transformer manufacturing in the U.S.

Table 5.4.7 Labor Markups for Liquid-Immersed and Dry-Type Manufacturers

Item description	Markup percentage	Rate per hour
Labor cost per hour*		$ 14.31
Indirect Production**	33%	$ 19.03
Overhead***	30%	$ 24.74
Fringe†	21%	$ 29.93
Assembly Labor Up-time††	43%	$ 42.77
Non-Production Mark-up†††	25%	$ 53.46
Cost of Labor Input to Software		**$ 53.46**

* Cost per hour is from U.S. Census Bureau, *1997 Economic Census of Industry*, published September 1999, Table 5, page 9. Data for NAICS code 3353111 "Power and distribution transformers, except parts" Production workers hours and wages.
** Indirect Production Labor (Production managers, quality control, etc.) as a percent of direct labor on a cost basis. Navigant Consulting, Inc. (NCI) estimate.
*** Overhead includes commissions, dismissal pay, bonuses, vacation, sick leave, and social security contributions. NCI estimate.
† Fringe includes pension contributions, group insurance premiums, workers compensation. Source: U.S. Census Bureau, *1997 Economic Census of Industry*, published September 1999, Table 3, page 8. Data for NAICS code 335311 "Power, Distribution and Specialty Transformer Manufacturing," Total fringe benefits as a percent of total compensation for all employees (not just production workers).
†† Assembly labor up-time is a factor applied to account for the time that workers are not assembling product and/or reworking unsatisfactory units. The markup of 42 percent represents a 70 percent utilization (multiplying by 100/70). NCI estimate.
††† Non-production markup reflects non-production costs, including selling, general, and administrative, R&D, interest payments, and profit factor markups. Source: US Industry Census Data for 1992 and 1997; SEC 10-K reports for Acme, Powell, Magnetek and Hammond; Manufacturer interviews, 2002.

There are several labor steps involved in manufacturing a liquid-immersed transformer. The Department prepared estimates of the amount of labor involved, some varying with the transformer design and others fixed on a per unit basis. These steps are described below, and the amount of time dedicated to each are given in Table 5.4.6.

- Cutting, Forming, and Annealing - this task involves cutting the core steel to lengths on a distributed-gap core cutting machine, forming the resulting "donut" of core steel into a rectangular shape in a hydraulic press, and then annealing the core in a high temperature annealing furnace. The labor involved in these activities is calculated based on the weight of core (pounds) multiplied by a constant, which varies with the lamination thickness of the core steel. For DL1, DL2, and DL4, on M6 designs the constant is 0.08, on M4 its 0.10, M3 is 0.125 and M2 is 0.16. For DL3 and DL5, on M6 designs the constant is 0.05, M4 is 0.07, M3 is 0.09, and M2 is 0.11. For the prefabricated cores - ZDMH and SA1 (Amorphous material), the labor for cutting, forming and annealing is set to zero.

- Primary Winding - this task encompasses the hours of labor necessary for winding the primary conductor of the transformer. It includes set-up time as well as winding time. The labor hours vary with the number of turns (per phase) for the primary winding. For DL1, DL2, and DL4 the winding time is 0.0001 hours per turn. For these smaller kVA ratings (and smaller cores), this rate is very low because some of the larger liquid-immersed manufacturers wind multiple coils simultaneously on the same winding machine. This manufacturing approach improves throughput and productivity at the facility. The rate of 0.0001 hours per turn equates to approximately one-third of a second per turn. On DL3 and DL5, due to the larger coil size associated with these units, the winding time is 0.002 hours per turn (approximately 7.2 seconds per turn).

- Secondary Winding - this task involves the hours of labor necessary for winding the secondary of the transformer. It includes set-up time as well as winding time. On a distribution transformer (step-down) the number of secondary turns is always less than the primary. For the liquid-immersed units which are taking a relatively high primary voltage and dropping to below 600V, the turns ratio can be as large as 100:1. For this reason, the hours per turn of the secondary are considerably higher than the primary both because there are fewer turns over which to amortize the set-up time as well as a slower winding rate for the secondary which has larger cross-sectional area than the primary. For DL1, DL2 and DL4, the hours per turn of the secondary are 0.015 (54 seconds per turn) and for DL3 and DL5, the hours per turn are 0.02 (72 seconds per turn).

- Lead Dressing - once a wound coil is taken off the winding machine, work must be performed on the leads to prepare them for the next manufacturing step. Enamel is removed to enable good electrical connection and an insulating tubing is slipped over the cable. This is a fixed amount of labor, and does not vary with efficiency or design. The estimated times are 0.5 hours for DL1 and DL4, 0.07 hours for DL2, 0.35 hours for DL3 and 1.0 hour for DL5.

- Coil Varnishing and Baking - once they are complete, the coils are vacuum dipped in varnish and baked in an oven to cure the varnish and enhance the integrity of the coil. This task varies slightly with kVA rating, but does not vary with efficiency. The estimated times are 0.10 hours for DL1, 0.07 hours for DL2, 0.15 hours for DL3, 0.17 hours for DL4 and 0.25 hours for DL5.

- Core Assembly ("Lacing") - this task involves assembling and banding the annealed wound core laminations around varnished windings. The annealed bundle of core steel is disassembled from the inside out by grabbing approximately 1/4 inch bundles, then reassembling the core steel around the coils. Once all the laminations are reassembled, the core material is then clamped to maintain the structure. The activity involves feeding a banding strip around the core material and using a locking clamp to compress and contain the core material. The labor rate varies with stack height and lamination thickness for each design. The time for core assembly is approximately 0.5 hours for DL1, 0.3 hours for DL2, 1.5 hours for DL3, 1 hour for DL4 and 3.5 hours for DL5.

- Tanking and Impregnating - this task involves inserting and fastening the core/coil assembly into the tank. Then, a vacuum is pulled and oil is introduced to the tank. The vacuum and oil step on round tanks is done through a lid attached to the top of the unit. On the rectangular and pad-mounted tanks, the vacuum is pulled in a chamber, thus it takes a little longer per unit. Finally, tap changers and bushings are mounted, and bolted connections made. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating and tank shape. The estimates of labor time for the five liquid-immersed design lines are: 0.5 hours for DL1, 0.11 hours for DL2, 0.3 hours for DL3, 0.62 hours for DL4 and 1.4 hours for DL5.

- Inspection - this activity involves verifying that the transformer is assembled properly and is up to manufacturer's quality specification. This task includes inspecting the lead dressing, lead tie-up, and other quality certification specifications. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. The estimates of labor time are 0.10 hours for DL1 and DL3, 0.05 hours for DL2, 0.15 hours for DL4 and 0.20 hours for DL5.

- Preliminary Test - this step involves conducting a test to ensure that the core/coil meets the specified turns ratio, polarity, core loss, etc. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. The estimates of labor time are 0.10 hours for DL1, DL3 and DL4; 0.03 hours for DL2 and 0.15 hours for DL5.

- Final Test - this activity involves testing of the final, assembled unit, with the core/coil assembly immersed in oil. This test verifies that the unit meets the guaranteed values, including core and coil losses, impedance, and dielectric tests. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. The estimates of labor time are 0.15 hours for DL1 and DL3, 0.07 hours for DL2, 0.20 hours for DL4 and 0.25 hours for DL5.

- Marking and Miscellaneous - this task involves preparing any extra markings around the bushings or on the surface of the transformer and other miscellaneous labor associated with preparing the finished transformer for the customer. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. The estimates of labor time are 0.28 hours for DL1, 0.07 hours for DL2, 0.35 hours for DL3, 0.31 hours for DL4, and 0.75 hours for DL5.

- Pallet Loading - this activity involves preparing the transformer for shipping to the customer. This includes loading the finished transformer onto a pallet, banding the transformer to the pallet, wrapping and all other necessary steps for shipping. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. The estimates of labor time are 0.27 hours for DL1, 0.06 hours for DL2, 0.5 hours for DL3 and DL4, and 3 hours for DL5.

Table 5.4.8 summarizes the estimates of labor time discussed in this section that were used for the five liquid-immersed units.

Table 5.4.8 Summary of Labor Times for Liquid-Immersed Units

Labor Activity	DL 1 *hrs.*	DL 2 *hrs.*	DL 3 *hrs.*	DL 4 *hrs.*	DL 5 *hrs.*
Cutting, Forming, & Annealing	~1.00	~0.75	~4.00	~3.00	~8.50
Primary Winding (hrs/turn)	0.0001	0.0001	0.002	0.0001	0.002
Secondary Winding (hrs/turn)	0.015	0.015	0.020	0.015	0.020
Lead Dressing	0.50	0.07	0.35	0.50	1.00
Baking Coils	0.10	0.07	0.15	0.17	0.25
Core Assembly	~0.50	~0.30	~1.50	~1.00	~3.50
Tanking and Impregnating	0.50	0.11	0.30	0.62	1.40
Inspection	0.10	0.05	0.10	0.15	0.20
Preliminary Test	0.10	0.03	0.10	0.10	0.15
Final Test	0.15	0.07	0.15	0.20	0.25
Pallet Loading	0.27	0.06	0.50	0.50	3.00
Marking and Misc.	0.28	0.07	0.35	0.31	0.75

- Core Stacking - this task involves the labor associated with stacking (assembling) the cut steel laminations into a distribution transformer core. The amount of labor for this task varies by kVA rating, stack height and whether the core is grain-oriented or non-oriented. Thus the labor for core stacking varies with efficiency of the transformer. Approximate labor hours for core stacking vary from a short as 0.15 hours / inch for a 25 kVA single-phase low-voltage to 0.9 hours / inch for a 2000 kVA three-phase medium-voltage.

- Primary Winding - this task encompasses the hours of labor necessary for winding the primary conductor of the transformer. It includes set-up time as well as winding time. The labor hours vary with the number of turns (per phase) for the primary winding. For DL6, the winding time is the quickest, with 0.001 hours/turn. DL7 is slightly longer with 0.0015 hours/turn. The 300kVA units, DL8, DL9 and DL11 all have the same 0.01 hours/turn. The 1500kVA units, DL10, DL12 and the 2000kVA DL13 all have the same winding time, 0.0125 hours/turn.

- Secondary Winding - this task involves the hours of labor necessary for winding the secondary of the transformer. It includes set-up time as well as winding time. The hours per turn of the secondary are considerably higher than the primary because there are fewer turns over which to amortize the set-up time as well as a slower winding rate for the secondary which has larger cross-sectional area. The hours per turn vary from 0.01 to 0.125, depending on the kVA rating (design line).

- Lead Dressing - once a wound coil is taken off the winding machine, work must be performed on the leads to prepare them for the next manufacturing step. Enamel is removed to enable good electrical connection and an insulating tubing is slipped over the cable. For a given kVA rating, this is a fixed amount of labor, and does not vary with efficiency or design. The range is from 0.15 to 1.0 hours per unit.

- Assembly - this task involves installing the wound cores onto the partially assembled core, and then lacing the top (yoke) laminations to complete the core. It also includes the time to set all the core clamps and complete the core/coil assembly. The Department assumed that the assembly time varies by kVA rating, but does not vary by design within a kVA rating. For example, the assembly time for a 1500kVA three-phase unit is estimated at 6 hours while the assembly time for a 75kVA three-phase unit is estimated at one hour.

- Inspection - this activity involves verifying that the transformer is assembled properly and is up to manufacturer's quality specification. This task includes inspecting the lead dressing, lead tie-up, and other quality certification specifications. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. The time estimates vary from 0.05 hours (3 minutes) for the smaller kVA ratings to 0.25 hours (15 minutes) for the larger units.

- Preliminary Test - this step involves conducting a test to ensure that the core/coil meets the specified turns ratio, polarity, core loss, etc. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. The estimates of labor time range from 0.05 hours (3 minutes) for the smaller kVA ratings to 0.5 hours (30 minutes) for the larger units.

- Final Test - this activity involves testing of the final, assembled unit, with the core/coil assembly immersed in oil. This test verifies that the unit meets the guaranteed values, including core and coil losses, impedance, and dielectric tests. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. Similar to the preliminary test, the labor time estimates range from 0.1 hours (6 minutes) for the smaller kVA ratings 0.75 hours (45 minutes) for the larger units.

- Marking and Miscellaneous - this task involves preparing any extra markings on the terminal board or on the surface of the transformer, and other miscellaneous labor associated with preparing the finished transformer for the customer. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. The labor estimate ranges from 0.20 hours at the low end to 2.2 hours at the higher kVA ratings.

- Packing - this activity involves preparing the transformer for shipping to the customer. This includes loading the finished transformer onto a pallet, banding the transformer to the pallet, wrapping and all other necessary steps for shipping. The time for this activity does not vary with design or efficiency, but it does vary by kVA rating. The time estimate ranges from 0.20 hours at the low end to 2.0 hours at the higher kVA ratings.

- Enclosure Manufacturing - this task encompasses a labor estimate for all activity associated with the cutting, forming, assembly, priming, painting, and preparation of the enclosure. This labor estimate varies with the kVA rating, spanning from 0.75 hours for the 25kVA single-phase up through 8 hours for the 1500 and 2000kVA cabinets.

Table 5.4.7 presents the hours of labor needed to complete each step in the manufacturing process for all design lines containing dry-type transformers.

Table 5.4.9 Summary Table of Labor Times for Dry-Type Units

Labor Activity	DL 6 *hrs.*	DL 7 *hrs.*	DL 8 *hrs.*	DL 9 *hrs.*	DL 10 *hrs.*	DL 11 *hrs.*	DL 12 *hrs.*	DL 13 *hrs.*
Core Stacking (hrs/inch)	0.15 - 0.25	0.25 - 0.35	0.28 - 0.38	0.45- 0.55	0.70	0.70	0.80	0.90
Primary Winding (hrs/turn)	0.001	0.0015	0.01	0.01	0.0125	0.01	0.0125	0.0125
Secondary Winding (hrs/turn)	0.01	0.011	0.035	0.035	0.125	0.035	0.125	0.125
Lead Dressing	0.15	0.25	0.50	0.60	1.00	0.60	1.00	1.00
Assembly	0.35	1.00	2.50	3.00	6.00	4.00	6.00	6.00
Inspection	0.05	0.05	0.10	0.10	0.25	0.10	0.25	0.25
Preliminary Test	0.05	0.05	0.10	0.10	0.50	0.15	0.50	0.50
Final Test	0.10	0.10	0.15	0.15	0.75	0.25	0.75	0.75
Enclosure Manufacturing	0.75	1.50	3.00	5.00	8.00	5.00	8.00	8.00
Packing	0.20	0.20	1.00	1.00	2.00	1.00	2.00	2.00
Marking and Misc.	0.20	0.20	0.60	0.70	2.20	0.80	2.20	2.20

5.5 RESULTS OF THE ANALYSIS ON EACH DESIGN LINE

This section provides a visual representation of the results of the engineering analysis. The scatter plots in this section show the relationship between the manufacturer's selling price and efficiency for each of the 13 design lines. Each dot on the plots represents one unique design created by the software at a given manufacturer's selling price and efficiency level. The placement of each dot (and the uniqueness of each design) is dictated by the design option combinations (core steel and windings), core shape, A/B combination and the variable design parameters generated by the design software. In addition to the results provided in this section, the Department also prepared additional scatter plots depicting results of the engineering analysis results for the 13 representative units, including watts of core and coil loss and the weight by efficiency (see Appendix 5A).

As discussed earlier in this chapter, the Department received several comments on the ANOPR analysis that material prices, and particularly core steel, were experiencing a rapid increase. Therefore, in addition to its analysis on a five year average material price (2000 through 2004) presented here, the Department also conducted a current price scenario of the first quarter 2005. The engineering analysis results of the Q1 2005 material price scenario are presented in Appendix 5C, along with a comparison between these material prices and the five year average. The Department also calculated a hypothetical low materials price scenario, which represents a 15% reduction over the 2002 materials prices (year in which M6 had the lowest $/pound between 2000 and 2004). The results of the low price scenario are included in the LCC spreadsheets, where they are used for an LCC sensitivity analysis.

Figure 5.5.1 presents a plot of the manufacturer selling prices and efficiency levels for the full database of designs for the representative unit from design line 1, a 50kVA single-phase liquid-immersed pad-mounted distribution transformer. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- NEMA's TP 1-2002 efficiency level of 98.9 percent is met by most M3 and M2 core designs. However, many of the M6 core designs exhibit efficiencies below this level.
- The amorphous metal (SA1) core extends the available efficiency for the transformers beyond 99.6 percent, but at a significant cost.

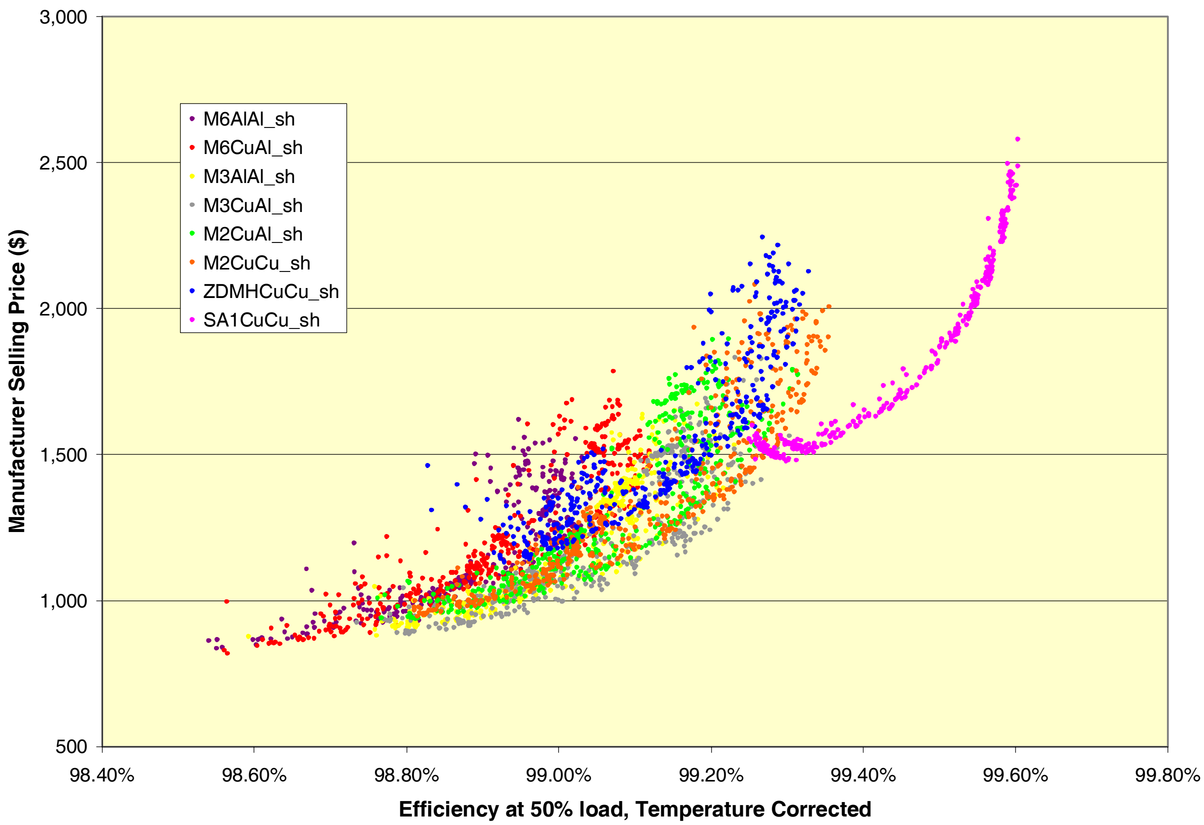

Figure 5.5.1 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 1

Figure 5.5.2 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 2, a 25kVA single-phase liquid-immersed pole-mounted distribution transformer. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- The NEMA TP 1-2002 standard of 98.7 percent can be achieved with several design option combinations, including M3CuAl and M3CuCu.
- In most cases, the maximum efficiency available with conventional silicon core steels is approximately 99.2 percent. However, the amorphous metal (SA1) provides efficiencies up to about 99.5 percent.

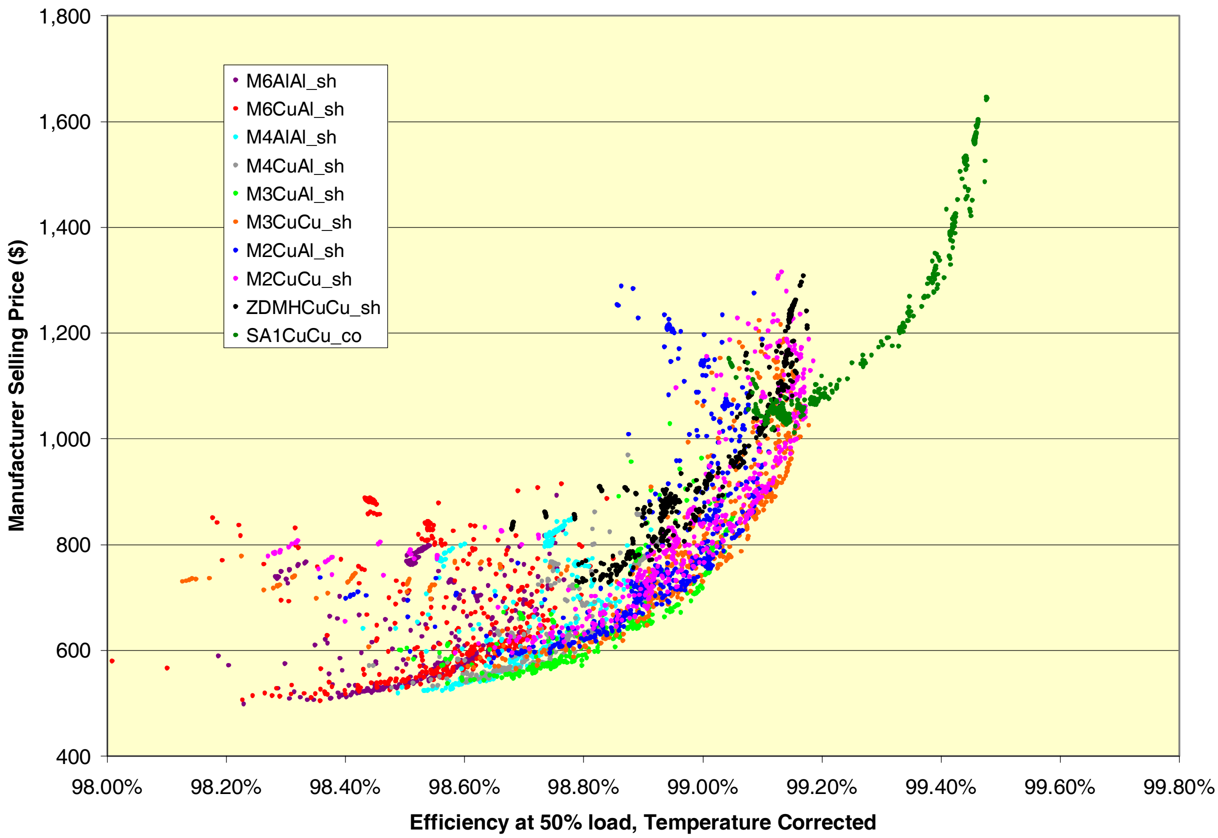

Figure 5.5.2 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 2

Figure 5.5.3 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 3, a 500kVA single-phase liquid-immersed distribution transformer with radiators. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- All design option combinations have designs that meet or exceed the NEMA TP 1-2002 efficiency of 99.3 percent.
- In most cases, the maximum efficiency available is limited to approximately 99.6 percent. However, the amorphous metal design option combination provides efficiencies up to about 99.75 percent, with an available range from about 99.35 percent to nearly 99.75 percent.

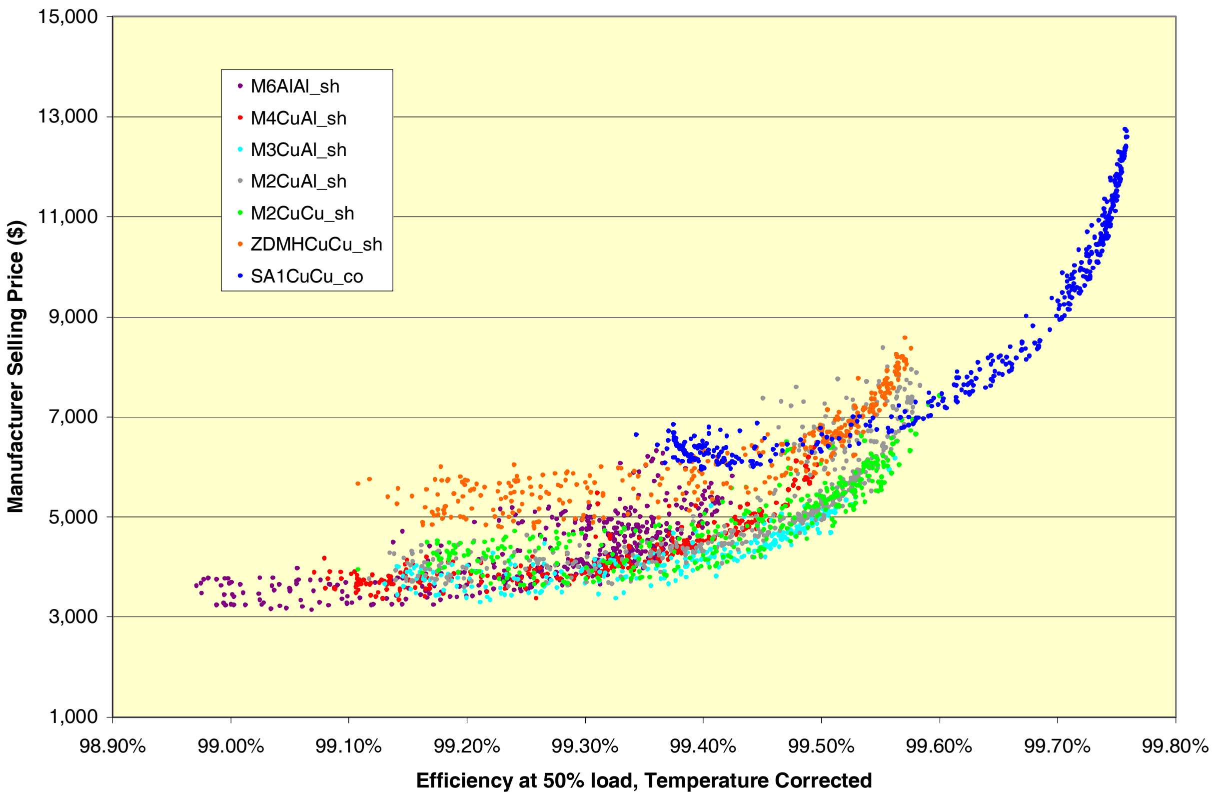

Figure 5.5.3 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 3

Figure 5.5.4 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 4, a 150kVA three-phase liquid-immersed distribution transformer. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- At the lower efficiencies, the M6 and M4 steel cores offer a low-cost option for increasing efficiency, but do not meet the NEMA TP 1-2002 efficiency standard of 98.9 percent.
- The amorphous metal design option combination extends the available efficiency for the transformers up to 99.6 percent, but at a significant cost.

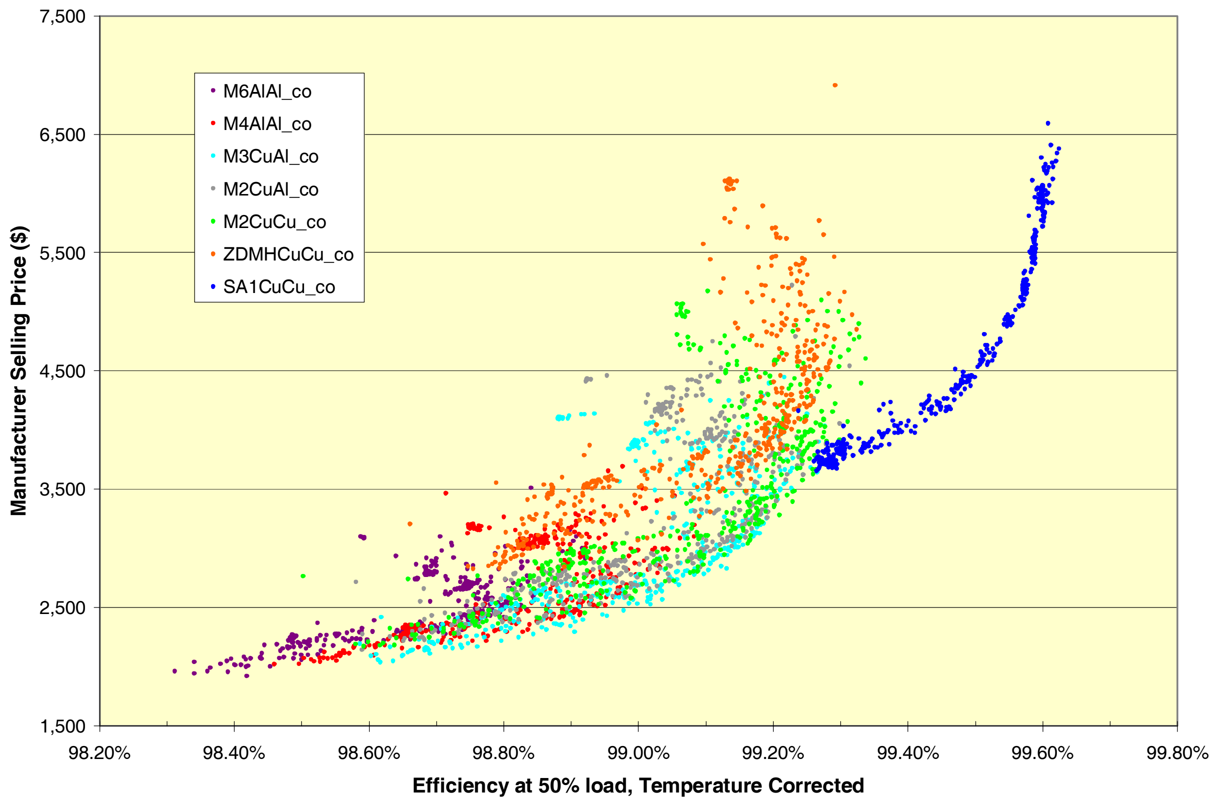

Figure 5.5.4 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 4

Figure 5.5.5 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 5, a 1500kVA three-phase liquid-immersed distribution transformer. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- Every design option combination has designs that meet the NEMA TP 1-2002 efficiency of 99.3 percent, however many of the M6 and M4 core designs exhibit efficiencies lower than 99.3 percent.
- Beyond 99.5 percent, the SA1 core provides additional efficiency with increased cost.

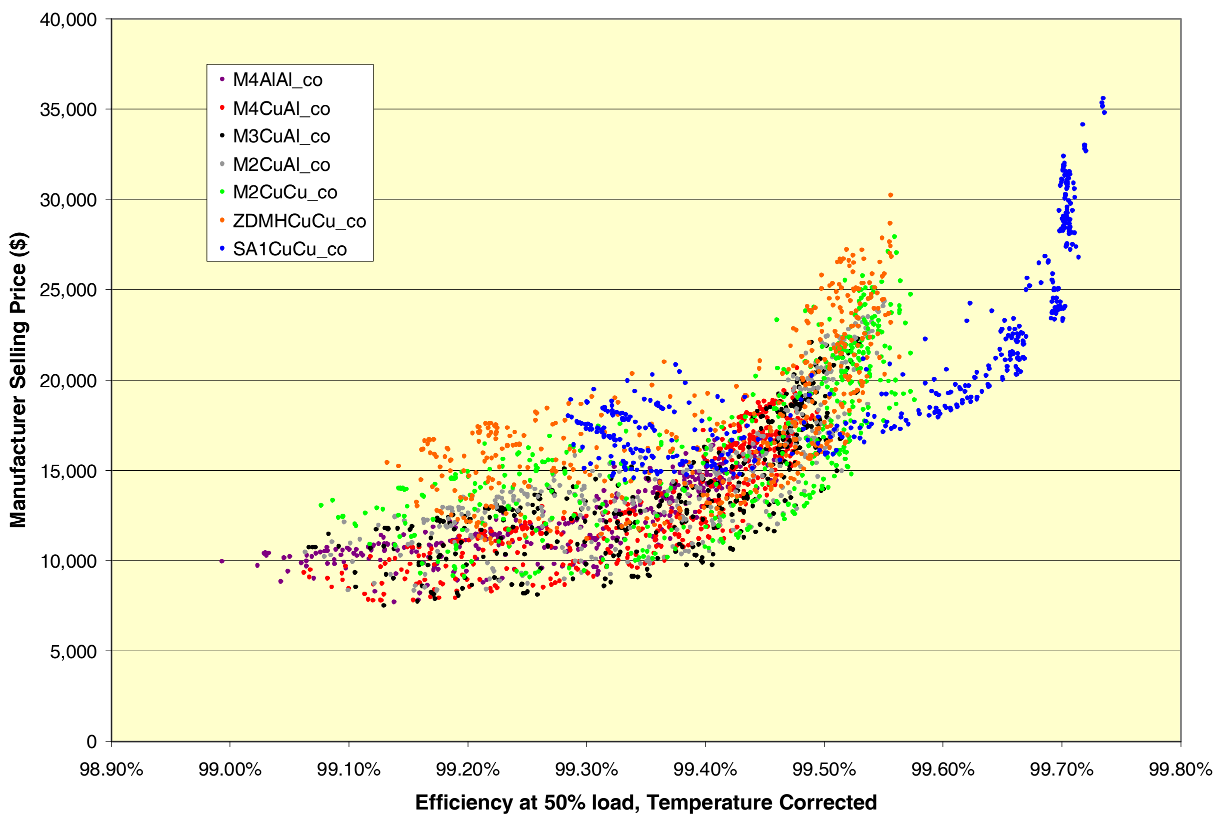

Figure 5.5.5 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 5

Figure 5.5.6 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 6, a 25kVA single-phase low-voltage dry-type transformer. The efficiency levels shown in this plot represent transformers at 35 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- The least-expensive cores, M43, M36, and M19, do not meet the minimum efficiency level for NEMA's TP 1-2002 for a 25kVA low-voltage, dry-type, single-phase of 98.0 percent.
- The H-O DR steel cores provide the highest efficiency but are limited to about 99.0 percent efficiency. At these higher efficiency levels, the cost of the transformers rises exponentially with little or no gain in efficiency.

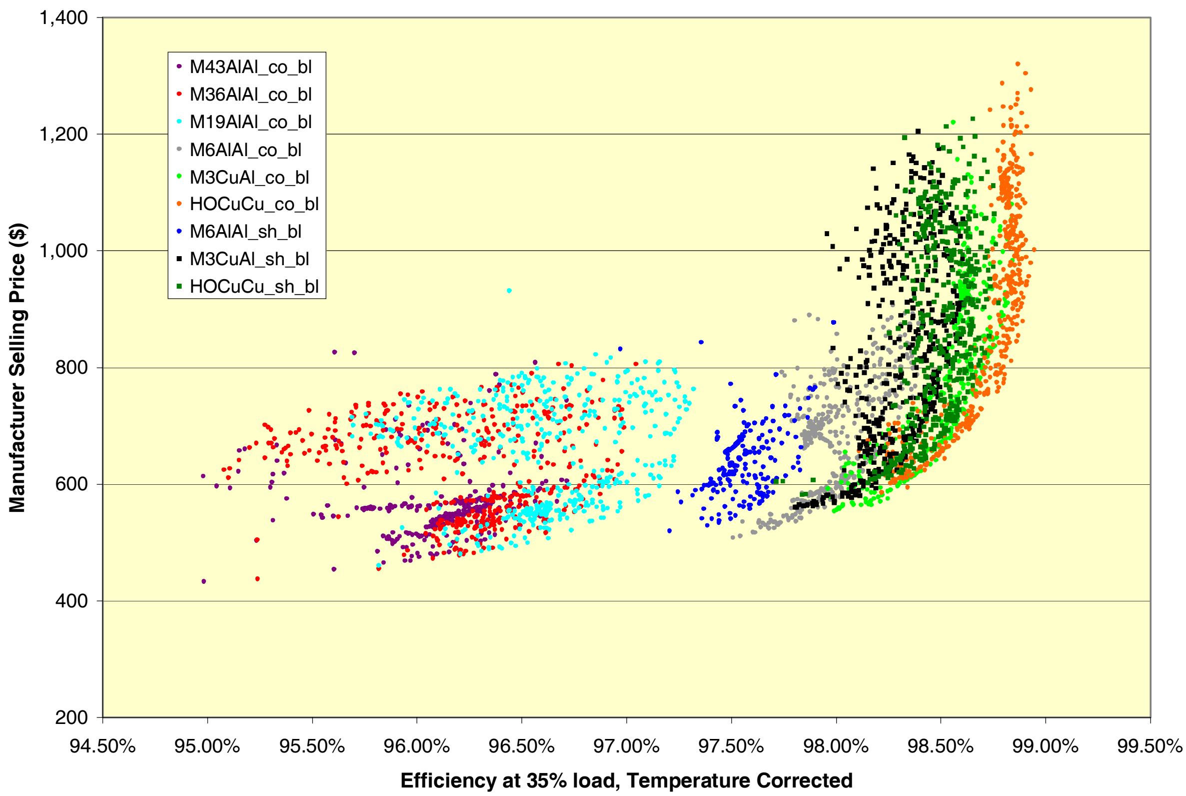

Figure 5.5.6 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 6

Figure 5.5.7 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 7, a 75kVA three-phase low-voltage dry-type transformer. The efficiency levels shown in this plot represent transformers at 35 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- The M3CuAl transformer has essentially the same costs and efficiency gains as the HOCuCu transformer. However, the H-O DR transformer provides a slightly higher efficiency than the M3 transformer.
- The M19 and M36 cores do not achieve the minimum efficiency rating of 98.0 percent under NEMA's TP 1-2002 for a 75kVA three-phase LV dry-type transformer.

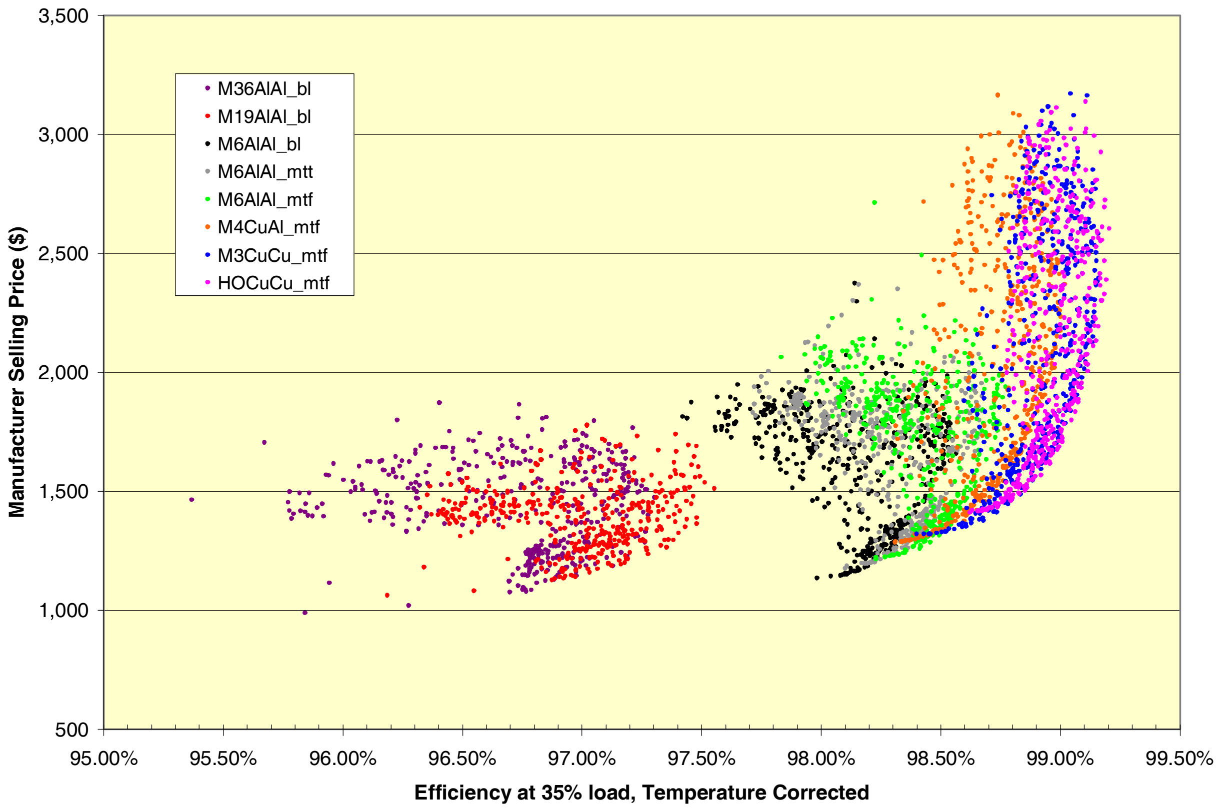

Figure 5.5.7 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 7

Figure 5.5.8 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 8, a 300kVA three-phase low-voltage dry-type transformer. The efficiency levels shown in this plot represent transformers at 35 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- The HOCuCu transformer does not appear to have any cost benefit over the M3CuAl transformer. At 99.0 percent efficiency, a transformer with the M3 steel core offers the least cost and at higher efficiencies has costs equal to those of the H-O DR core steel.
- The M19 core steel can not reach the minimum efficiency of 98.6 percent under NEMA's TP 1-2002.

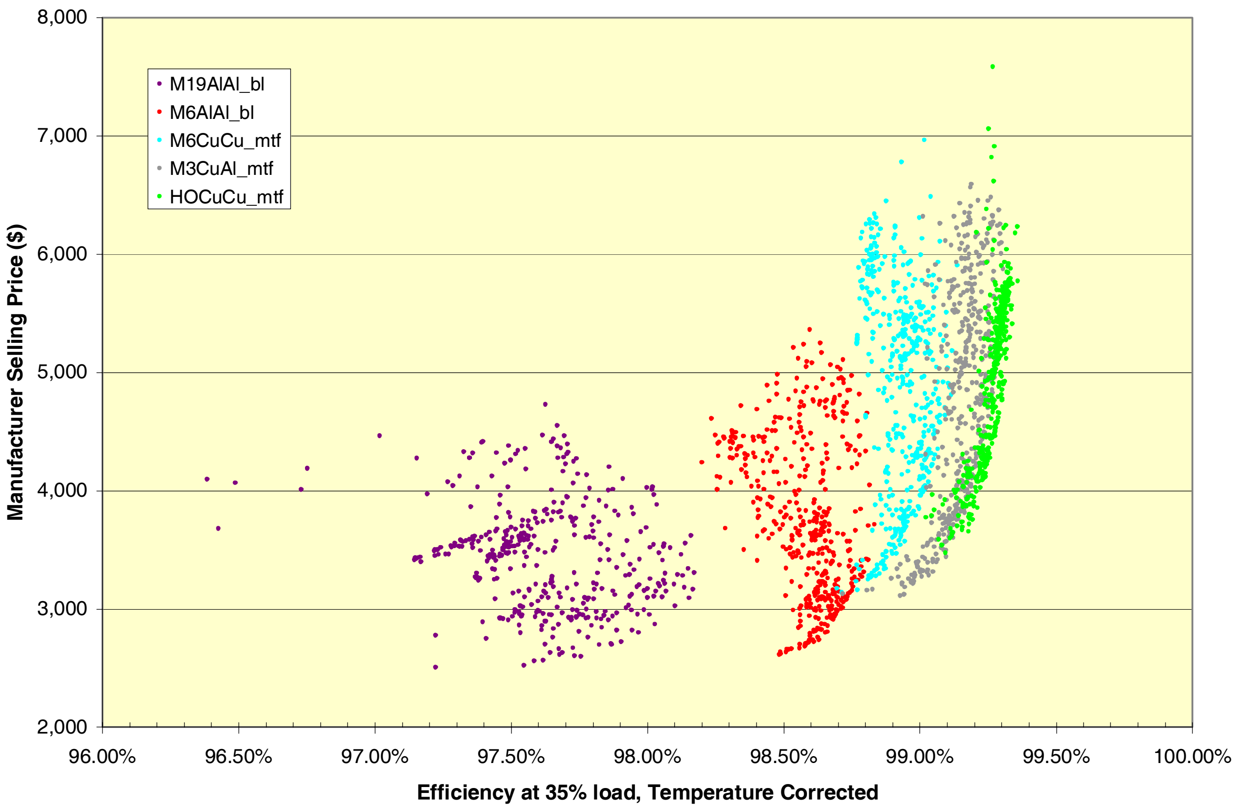

Figure 5.5.8 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 8

Figure 5.5.9 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 9, a 300kVA three-phase medium-voltage dry-type transformer with a 45kV BIL. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- NEMA's TP 1-2002 efficiency level for this unit is 98.6 percent efficient. This level can be achieved by using M6 or better core steels.
- Rapid increase in price is realized in the M3 and H-O DR core steels, as the efficiency level increases. For example, moving a fraction of an efficiency level (e.g., from 99.00 percent to 99.5 percent) can almost double the price.

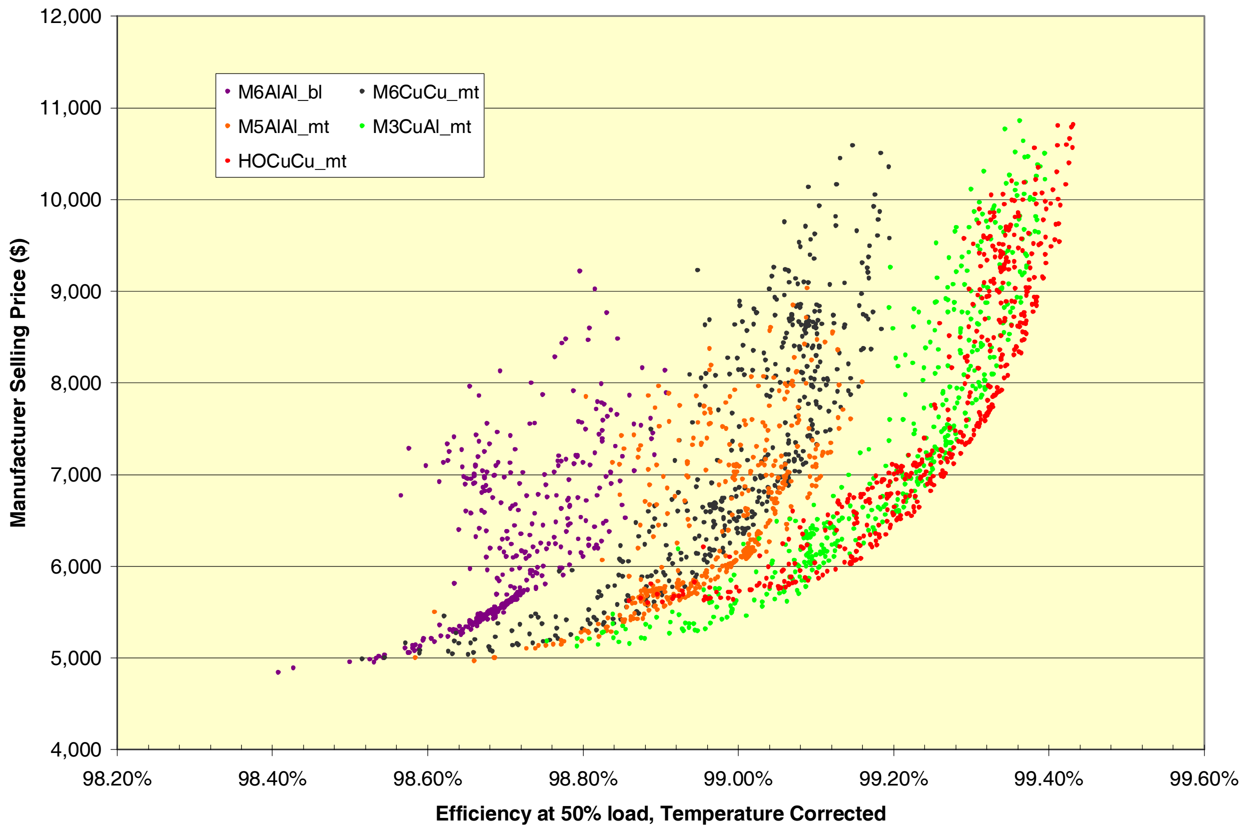

Figure 5.5.9 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 9

Figure 5.5.10 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 10, a 1500kVA three-phase medium-voltage dry-type transformer with a 45kV BIL. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- NEMA's TP 1-2002 efficiency level of 99.1 percent is met by M4, M3 and HO core steel designs.
- As the efficiency increases, the laser-scribed (H-O DR) and M3 steel cores have similar costs.

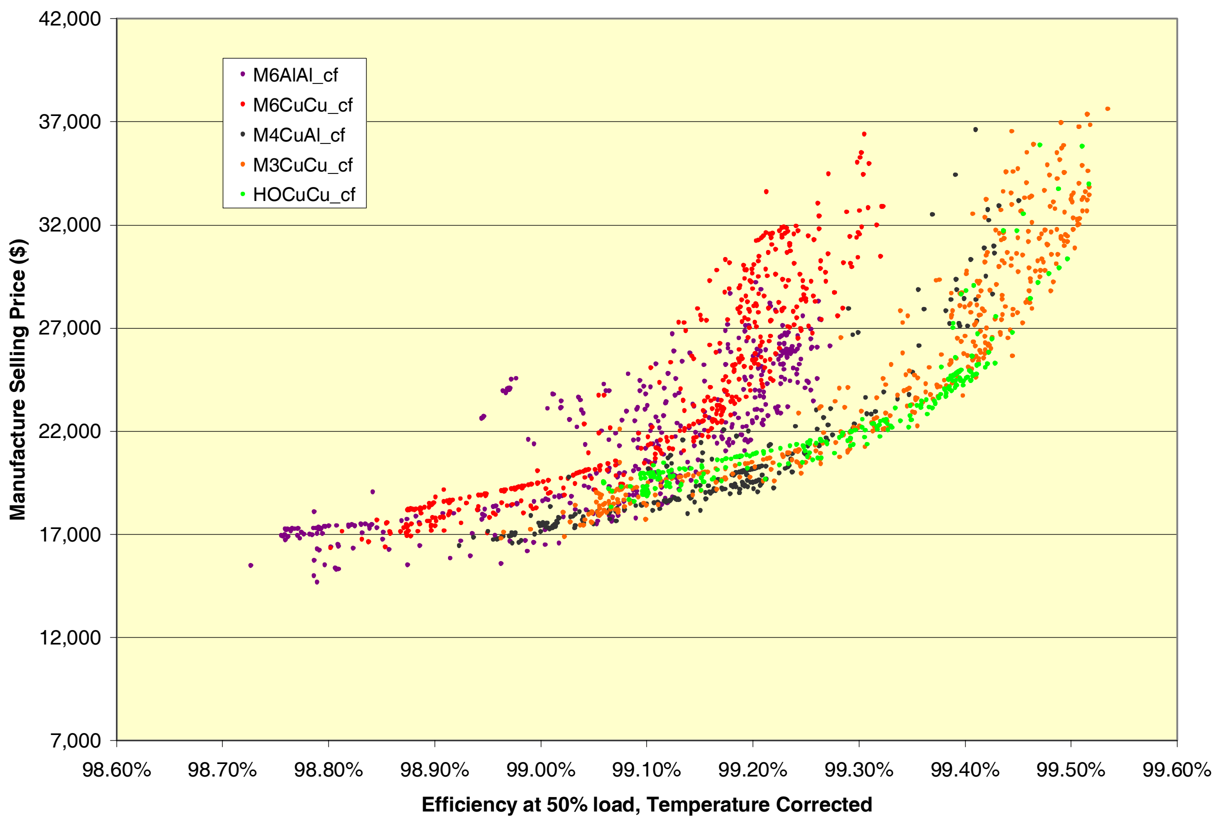

Figure 5.5.10 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 10

Figure 5.5.11 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the design line 11, a 300kVA three-phase medium-voltage dry-type transformer with a 95kV BIL. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load. The following observations can be made about this scatter plot:

- The least-cost high-efficiency design path at 50 percent load varies between the M3, M4, and H-O DR cores steel design option combinations.
- The M6 cores offer the least-cost options only at the lowest efficiency levels. In general, the transformers that use the M6 core steel are not the most cost-effective option available, and many of the M6 designs do not meet the NEMA TP 1-2002 efficiency level of 98.5 percent.

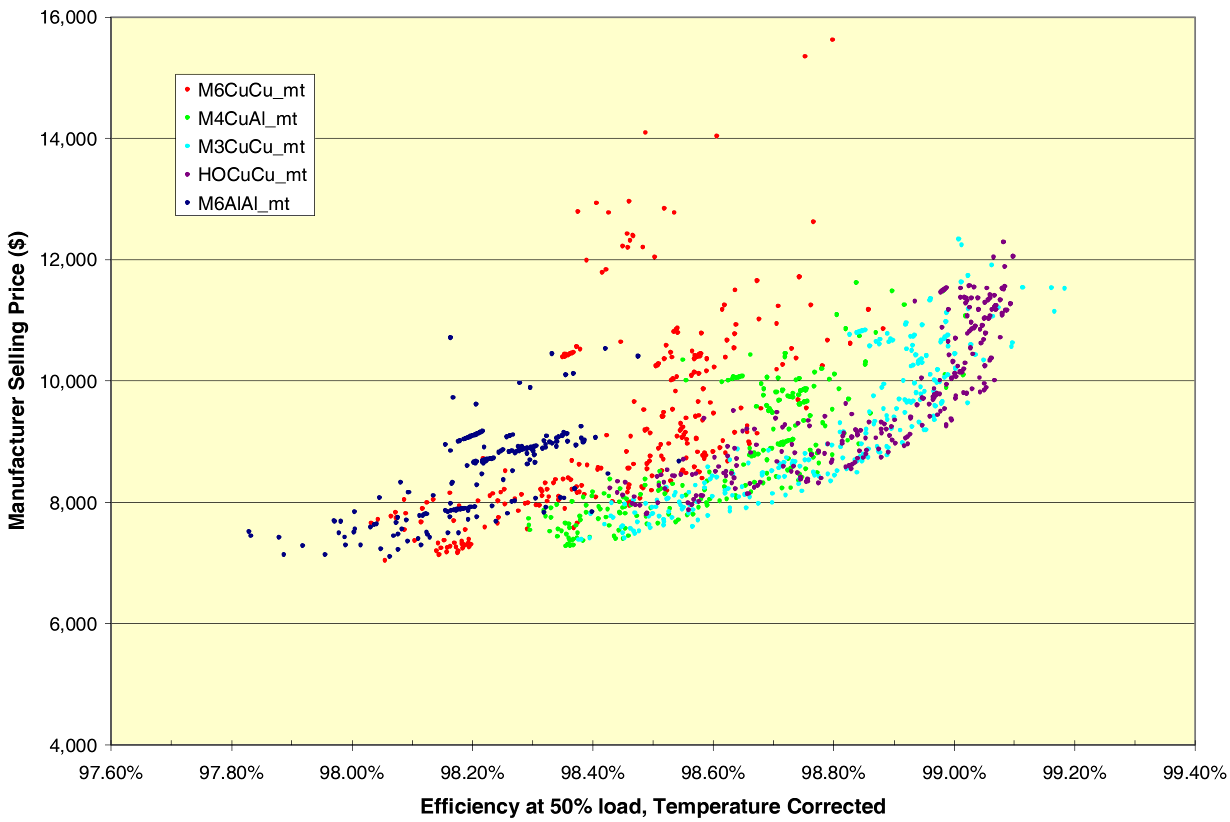

Figure 5.5.11 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 11

Figure 5.5.12 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 12, a 1500kVA three-phase medium-voltage dry-type transformer with a 95kV BIL. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load. The following observations can be made about this scatter plot:

- NEMA's TP 1-2002 efficiency level of 99.0 percent is met by M4, M3 and HO core steel designs.
- Above 99.3 percent efficiency, the H-O DR steel design option combination has a slight cost advantage over the M3 core.

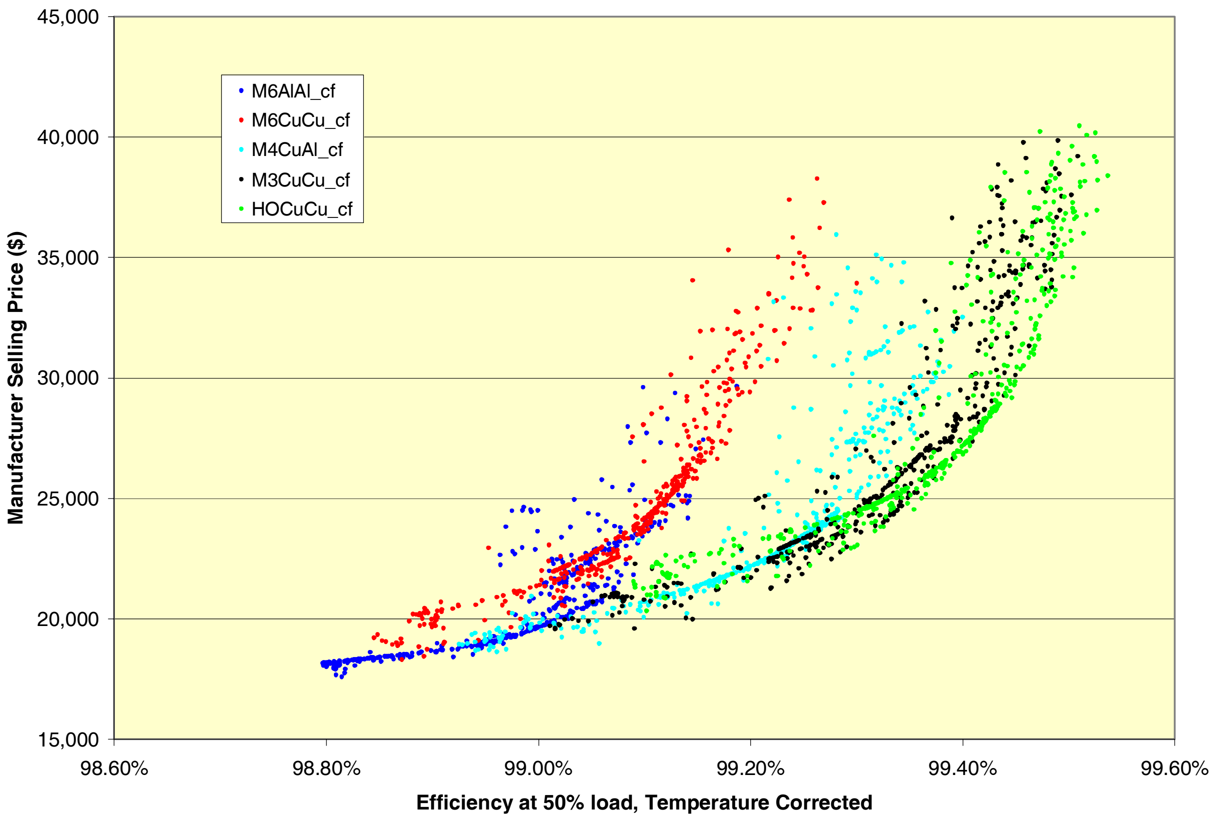

Figure 5.5.12 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 12

Figure 5.5.13 presents a plot of the manufacturer sales prices and efficiency levels for the full database of designs for the representative unit from design line 13, a 2000kVA three-phase medium-voltage dry-type transformer with a 125kV BIL. The efficiency levels shown in this plot represent transformers at 50 percent of nameplate load and are corrected for temperature. The following observations can be made about this scatter plot:

- NEMA's TP 1-2002 efficiency level of 99.0 percent is met by all core steel design option considerations considered by the Department.
- At efficiency levels of 99.3 percent and above, the M3 steel core and H-O DR steel cores have similar costs and efficiency gains.

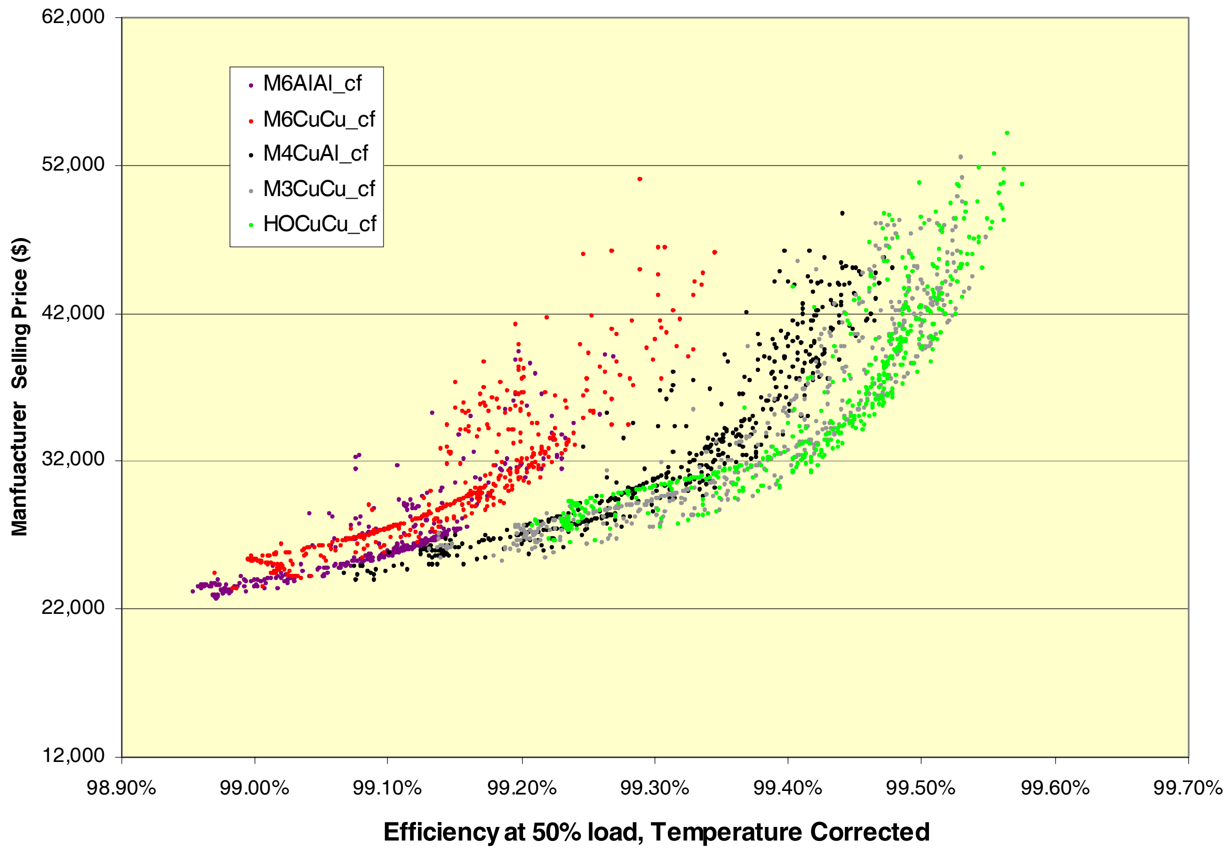

Figure 5.5.13 Scatter Plot of Manufacturer Selling Price and Efficiency for Design Line 13

5.6 SIX EXAMPLE TRANSFORMER DESIGNS AND COST BREAKDOWNS

This section presents some of the OPS transformer designs from the Department's Engineering Analysis database. As discussed earlier, to prepare a cost-efficiency relationship on selected representative units, the Department contracted Optimized Program Service (OPS), a software company specializing in transformer design since 1969. Using a range of input parameters and material prices, more than 45,000 transformer designs were created by OPS for the Department's analysis. For each design, the software generates specific information about the core and coil, including physical characteristics, dimensions, material requirements and mechanical clearances, as well as a complete electrical analysis of the final design. For information on OPS and their software, visit their website: http://www.opsprograms.com/home.html

To illustrate the typical output from the OPS software, two designs from each of the three superclasses (*i.e.*, liquid-immersed, low-voltage dry-type and medium-voltage dry-type) are presented in this section. As these practical designs illustrate, the software output is used to create a bill of materials, which is marked-up to arrive at the manufacturer's selling price. The OPS software provides an electrical analysis including efficiency, which, when plotted with the manufacturer's selling price, constitutes the primary output of the engineering analysis.

The six distribution transformers presented are two each from three design lines - 1, 7 and 12. Across all the design lines, the complete database of designs contains 46,102 distribution transformer specification and winding sheets, bills of materials, and performance reports. This design database is then used by the LCC analysis (see Chapter 8) as it simulates purchases of distribution transformers in the marketplace.

Design Line 1: 50 kVA single-phase, liquid-immersed

- M6 core steel with an aluminum primary and secondary windings (M6AlAl) at a $0.00 A and a $0.00 B evaluation formula.
- M3 core steel with a copper primary winding and an aluminum secondary winding (M3CuAl) at a $1.50 A and a $0.38 B evaluation formula.

Design Line 7: 75 kVA three-phase, low-voltage dry-type

- M6 buttlap core steel with aluminum primary and secondary windings (M6AlAl) at a $0.00 A and a $0.00 B evaluation formula.
- M6 t-mitered core steel with aluminum primary and secondary windings (M6AlAl) at a $1.50 A and a $0.14 B evaluation formula.

Design Line 12: 1500 kVA three-phase, medium-voltage dry-type

- M6 core steel with aluminum primary and secondary windings (M6AlAl) at a $0.00 A and a $0.00 B evaluation formula.
- M3 core steel with copper primary and secondary windings (M3CuCu) at a $0.50 A and a $0.08 B evaluation formula.

For the six designs presented, the design detail report is followed by a bill of materials showing the cost calculation, and a pie chart providing a breakdown of the final selling price.

5.6.1 Design Details Report for Non-Evaluated Transformer from Design Line 1

A design specification report for a 50kVA single-phase liquid-immersed transformer appears below. This design incorporates M6 core steel, with an aluminum primary and an aluminum secondary. The evaluation factors for this design are $0.00 A and $0.00 B. The bill of materials and associated breakdown of costs for this design are also reported, after the design and electrical analysis reports.

```
 OPTIMIZED PROGRAM SERVICE

                   CLEVELAND OHIO            101800
                       2005- 3- 1     5:40: 6
DG-CORE       SHELL   TYPE TRANSFORMER                NL1PM6ALAL

FREQUENCY    60.0             KVA RATING     50.00 @ 100.00% DUTY CYCLE

CORE DG-M6          M 6                                 THICKNESS .0140

  D: 6.738 E: 2.073 F: 3.104 G: 7.476  EFF. AREA  26.952 WEIGHT 203.850

WINDING FORM: INS. DIM.  6.988 X  4.331  THICKNESS  .072  LENGTH  6.976

                         COIL SPECIFICATIONS
                         -------------------

WNDG            WIRE            LENGTH   MEAN TURNS  MARGIN      WT
----------------------------------------------------------------------
S1         .0267X 6.2262   AL      31.83      25.47     .375      6.204
P1        1 #14.5 ROUND    AL    5643.34      35.83     .375     18.182
S2         .0267X 6.2262   AL      57.67      46.13     .375     11.238

NUMBER OF COILS  1               TOTAL BARE CONDUCTOR WEIGHT    35.558

WNDG  TURNS  LO TAP  HI TAP  LAYRS   T/L   LAYR INS   SEC. INS    BUILD
----------------------------------------------------------------------
S1      15.0                 15      1.0  1(.00500)  1(.03000)     .471
P1    1800.0  1710.0  1890.0 21     92.0  3(.00500)  1(.10000)    1.677
S2      15.0                 15      1.0  1(.00500)  1(.05000)     .471

                                                TOTAL BUILD(%)  92.51

WNDG                TAPS: TURNS( VOLTS)
----------------------------------------------------------
P1    1755.0( 14040.00)  1845.0( 14760.00)  1890.0( 15120.00)


WNDG    INTERNAL DUCTS(100.00) %EFF  EXTERNAL DUCTS(100.00) %EFF
----------------------------------------------------------------
S1      3  .125 X  .125 IN.  END
P1      6  .125 X  .125 IN.  END         .125 X  .125 IN.  END
S2      1  .125 X  .125 IN.  END         .125 X  .125 IN.  END
```

ELECTRICAL ANALYSIS

WNDG	FULL-LOAD VOLTS	TAP VOLTS LOW	TAP VOLTS HIGH	TEST KV	LOAD CURRENT	RESIST. @20 C.	CURRNT DENS.	%REG
P1	14400.00	13680.00	15120.00	34.5	3.541	27.52329	1293.	
S1	118.32			10.0	208.330	.00256	1253.	1.4
S2	117.77			10.0	208.330	.00463	1253.	1.9

	F.L.	N.L.		
FLUX DENS.	17.120	17.262	LEAKAGE INDUCTANCE MHYS	217.723
CORE LOSS	174.699	179.762	POWER FACTOR	1.0000
COIL LOSS	828.787	.028	IMPEDANCE %	2.54
EXCIT. VA	367.167	417.373	EFFICIENCY %	98.03
EXCIT. CURR.	.025	.029	TANK OIL GAL	41.86

AMBIENT TEMP.	20.00	NOMINAL LENGTH	14.50
TEMP.RISE	65.00	NOMINAL DEPTH	16.20
OPERATING TEMP.	85.00	NOMINAL HEIGHT	11.62

COND. I^2R LOSS = 806.3795
COND. EDDY CURRENT LOSS = 2.2476
OTHER STRAY LOSS = 20.1595
K VALUE = 1.0000

%LOAD	%REG	%EFF	%IR	%IX	%IZ	COIL LOSS	TEMP. RISE
25	.35	98.24	.341	.504	.608	45.690	28.6
35	.50	98.49	.484	.703	.854	90.911	33.6
50	.75	98.54	.717	1.004	1.234	192.395	44.2
65	1.03	98.43	.980	1.307	1.633	341.577	58.6
75	1.22	98.32	1.156	1.509	1.901	464.858	65.0
100	1.64	98.03	1.545	2.018	2.542	828.772	65.0
125	2.07	97.70	1.938	2.531	3.188	1299.377	65.0

Table 5.6.1 provides the bill of materials which was calculated from the OPS design details report. This bill of materials uses the raw material prices given in this Chapter for fixed and variable materials used in building the transformer. These materials are then marked-up at the bottom of the table to arrive at the manufacturer's selling price. This table provides the bill of materials for a non-evaluated transformer from design line 1, a 50kVA single-phase, liquid-immersed, pad-mount M6 design, with an aluminum primary and an aluminum secondary. This design was generated using a \$0.00A and \$0.00B.

Table 5.6.1 Bill of Materials for Non-Evaluated Transformer from Design Line 1

Bill of Materials and Labor for liquid-immersed, single-phase, pad-mount, 50kVA				
A$ Input	$0.00			
B$ Input	$0.00			
Efficiency at 50% load	98.56%			
Material item	**Type**	**quantity**	**$ each**	**$ total**
Core steel* (lb)	M6-.014	204	$ 0.70	$ 143.49
Primary winding* (lb)	Aluminum wire, formvar, round #9-17	18	$ 1.43	$ 26.00
Secondary windings* (lb)	Aluminum strip, thickness range 0.02-0.045	17	$ 1.54	$ 26.90
Winding form & insulation* (lb)	Kraft insulating paper with diamond adhesive	4	$ 1.59	$ 5.59
Oil (gal)	-	42	$ 1.71	$ 71.57
Tank	-	1	$ 132.95	$ 132.95
Core clamp	-	1	$ 15.00	$ 15.00
Nameplate	-	1	$ 0.65	$ 0.65
Bushings	HV & LV	1	$ 34.00	$ 34.00
Misc. hardware	-	1	$ 10.00	$ 10.00
Scrap factor		1.0%		$ 2.02
Total Material Cost				$ 468.17
Labor item		**hours**	**rate**	**$ total**
Lead dressing		0.50	42.77	$ 21.39
Inspection		0.10	42.77	$ 4.28
Baking coils		0.10	42.77	$ 4.28
Tanking and impregnating		0.50	42.77	$ 21.39
Preliminary test		0.10	42.77	$ 4.28
Final test		0.15	42.77	$ 6.42
Pallet loading		0.27	42.77	$ 11.55
Marking and miscellaneous		0.28	42.77	$ 11.98
Winding the primary		0.19	42.77	$ 8.08
Winding the secondary		0.45	42.77	$ 19.25
Cutting, forming, and annealing		0.38	42.77	$ 16.31
Core assembly		0.29	42.77	$ 12.23
Handling and slitting factor (on material)		1.50%		$ 3.03
Total Labor		3.306	42.77	$ 144.44
Manufacturing Cost (Material + Labor)				$ 612.61
Factory Overhead (Materials only)		12.5%		$ 58.52
Non-production Cost Markup		25.0%		$ 167.78
Manufacturer Selling Price				$ 838.91

* indicates those items to which the scrap factor (1.0%) and the handling and slitting factor (1.5%) are applied.

This bill of materials is based on non-rounded core dimensions.

Figure 5.6.1 provides a summary of the costs contributing to the total selling price of the non-evaluated transformer from design line 1. For this design, approximately 56 percent of the final manufacturer selling price is direct material and scrap. Labor accounts for 17 percent of the price, and together, the factory overhead and selling price account for 27 percent.

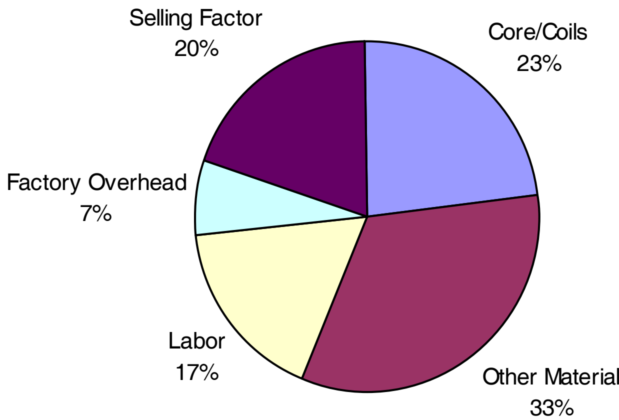

Figure 5.6.1 Manufacturer Selling Price Breakdown, Non-Evaluated Transformer from Design Line 1

5.6.2 Design Details Report for Evaluated Transformer from Design Line 1

A design specification report for a 50kVA single-phase liquid-immersed transformer appears below. This design incorporates M3 core steel, with a copper primary and an aluminum secondary. The evaluation factors for this design are $1.50 A and $0.38 B. The bill of materials and associated breakdown of costs for this design are also reported, after the design and electrical analysis reports.

```
OPTIMIZED PROGRAM SERVICE

                   CLEVELAND OHIO            101800
                       2005- 3- 1     8:52:41
DG-CORE        SHELL   TYPE TRANSFORMER                NL1PM3CUAL

FREQUENCY    60.0             KVA RATING     50.00 @ 100.00% DUTY CYCLE

CORE DG-M3          M 3                               THICKNESS .0090

  D: 7.635 E: 1.786 F: 3.048 G: 7.372  EFF. AREA  25.909 WEIGHT 188.488

WINDING FORM: INS. DIM.  7.885 X  3.758  THICKNESS  .072  LENGTH  6.872
```

COIL SPECIFICATIONS

WNDG	WIRE		LENGTH	MEAN TURNS	MARGIN	WT
S1	.0305X 6.1220	AL	35.24	26.43	.375	7.697
P1	1X 1 #16 ROUND	H CU	6087.06	36.23	.375	45.437
S2	.0305X 6.1220	AL	61.30	45.97	.375	13.387

NUMBER OF COILS 1 TOTAL BARE CONDUCTOR WEIGHT 66.520

WNDG	TURNS	LO TAP	HI TAP	LAYRS	T/L	LAYR INS	SEC. INS	BUILD
S1	16.0			16	1.0	1(.00500)	1(.03000)	.563
P1	1920.0	1824.0	2016.0	19	107.0	4(.00500)	1(.10000)	1.423
S2	16.0			16	1.0	1(.00500)	1(.05000)	.563

TOTAL BUILD(%) 91.85

WNDG	TAPS: TURNS(VOLTS)		
P1	1872.0(14040.00)	1968.0(14760.00)	2016.0(15120.00)

WNDG	INTERNAL DUCTS(100.00)	%EFF	EXTERNAL DUCTS(100.00)	%EFF
S1	3 .125 X .125 IN.	END		
P1	6 .125 X .125 IN.	END	.125 X .125 IN.	END
S2	1 .125 X .125 IN.	END	.125 X .125 IN.	END

ELECTRICAL ANALYSIS

WNDG	FULL-LOAD VOLTS	TAP VOLTS LOW	TAP VOLTS HIGH	TEST KV	LOAD CURRENT	RESIST. @20 C.	CURRNT DENS.	%REG
P1	14400.00	13680.00	15120.00	34.5	3.532	25.60013	1824.	
S1	118.40			10.0	208.330	.00253	1118.	1.3
S2	117.91			10.0	208.330	.00439	1118.	1.8

	F.L.	N.L.		
FLUX DENS.	16.706	16.836	LEAKAGE INDUCTANCE MHYS	245.843
CORE LOSS	105.561	108.891	POWER FACTOR	1.0000
COIL LOSS	779.995	.008	IMPEDANCE %	2.70
EXCIT. VA	219.090	238.628	EFFICIENCY %	98.26
EXCIT. CURR.	.015	.017	TANK OIL GAL	41.23

AMBIENT TEMP.	20.00	NOMINAL LENGTH	13.24
TEMP.RISE	65.00	NOMINAL DEPTH	16.98
OPERATING TEMP.	85.00	NOMINAL HEIGHT	10.94

COND. I^2R LOSS = 758.5084
COND. EDDY CURRENT LOSS = 2.5240

OTHER STRAY LOSS	=	18.9627
K VALUE	=	1.0000

%LOAD	%REG	%EFF	%IR	%IX	%IZ	COIL LOSS	TEMP. RISE
25	.33	98.81	.313	.565	.646	41.814	21.3
35	.47	98.92	.446	.791	.908	83.412	26.5
50	.69	98.88	.663	1.130	1.310	176.975	37.5
65	.95	98.72	.907	1.471	1.728	314.794	52.2
75	1.15	98.58	1.088	1.700	2.018	435.534	64.2
100	1.55	98.26	1.461	2.273	2.702	779.984	65.0
125	1.96	97.92	1.832	2.851	3.389	1222.869	65.0

Table 5.6.2 provides the bill of materials which was calculated from the OPS design details report. This bill of materials uses the raw material prices given in this Chapter for fixed and variable materials used in building the transformer. These materials are then marked-up at the bottom of the table to arrive at the manufacturer's selling price. This table provides the bill of materials for an evaluated transformer from design line 1, a 50kVA single-phase, liquid-immersed, pad-mount M3 design, with a copper primary and an aluminum secondary. This design was generated using a $1.50A and $0.38B.

Table 5.6.2 Bill of Materials for Evaluated Transformer from Design Line 1

Bill of Materials and Labor for liquid-immersed, single-phase, pad-mount, 50kVA				
A$ Input		$1.50		
B$ Input		$0.38		
Efficiency at 50% load		98.87%		
Material item	**Type**	**quantity**	**$ each**	**$ total**
Core steel* (lb)	M3-.009	188	$ 0.80	$ 150.79
Primary winding* (lb)	Copper wire, formvar, round #10-20	45	$ 1.55	$ 70.29
Secondary windings* (lb)	Aluminum strip, thickness range 0.02-0.045	21	$ 1.54	$ 32.52
Winding form & insulation* (lb)	Kraft insulating paper with diamond adhesive	4	$ 1.59	$ 6.98
Oil (gal)	-	41	$ 1.71	$ 70.50
Tank	-	1	$ 131.88	$ 131.88
Core clamp	-	1	$ 15.00	$ 15.00
Nameplate	-	1	$ 0.65	$ 0.65
Bushings	HV & LV	1	$ 34.00	$ 34.00
Misc. hardware	-	1	$ 10.00	$ 10.00
Scrap factor		1.0%		$ 2.61
Total Material Cost				$ 525.22
Labor item		**hours**	**rate**	**$ total**
Lead dressing		0.50	42.77	$ 21.39
Inspection		0.10	42.77	$ 4.28
Baking coils		0.10	42.77	$ 4.28
Tanking and impregnating		0.50	42.77	$ 21.39
Preliminary test		0.10	42.77	$ 4.28
Final test		0.15	42.77	$ 6.42
Pallet loading		0.27	42.77	$ 11.55
Marking and miscellaneous		0.28	42.77	$ 11.98
Winding the primary		0.20	42.77	$ 8.62
Winding the secondary		0.48	42.77	$ 20.53
Cutting, forming, and annealing		0.55	42.77	$ 23.41
Core assembly		0.26	42.77	$ 11.23
Handling and slitting factor (on material)		1.50%		$ 3.91
Total Labor		3.491	42.77	$ 153.24
Manufacturing Cost (Material + Labor)				$ 678.46
Factory Overhead (Materials only)		12.5%		$ 65.65
Non-production Cost Markup		25.0%		$ 186.03
Manufacturer Selling Price				$ 930.14

* indicates those items to which the scrap factor (1.0%) and the handling and slitting factor (1.5%) are applied.

This bill of materials is based on non-rounded core dimensions.

Figure 5.6.2 provides a summary of the costs contributing to the total selling price of the evaluated transformer from design line 1. For this design, approximately 57 percent of the final manufacturer selling price is direct material and scrap. Labor accounts for 16 percent of the price, and together, the factory overhead and selling price account for 27 percent.

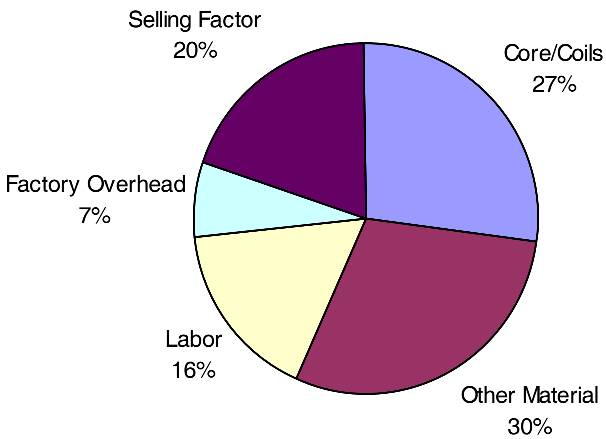

Figure 5.6.2 Manufacturer Selling Price Breakdown, Evaluated Transformer from Design Line 1

5.6.3 Design Details Report for Non-Evaluated Transformer from Design Line 7

The following design report provides information on one of several designs prepared to study the representative unit from design line 7. This is a 75kVA, three-phase, low-voltage, dry-type unit. The design shown here (out of the 4,144 designs in the database) is for M6 buttlap core steel with aluminum primary and secondary windings, and a $0.00 A and $0.00 B.

```
OPTIMIZED PROGRAM SERVICE

                   CLEVELAND OHIO            101800
                       2005- 3-12    10:28: 6
STRIP         3-PHASE TYPE TRANSFORMER               L7M6aa-BL

FREQUENCY    60.0            KVA RATING     74.94 @ 100.00% DUTY CYCLE

CORE  3.565" STRP  STACK  5.170            GRADE M 6    THICKNESS .0140

WINDOW:   2.685 X  9.432     EFF. AREA   17.787    WEIGHT   309.153

WINDING FORM:INS. DIM.  3.690 X  5.295  THICKNESS  .070  LENGTH  9.307
```

COIL SPECIFICATIONS

WNDG	WIRE			LENGTH	MEAN TURNS	MARGIN	WT
S1	.1731X	.6924	AL	44.65	21.43	.250	6.174
P1	.0934X	.3736	AL	269.40	30.79	.250	10.755

NUMBER OF COILS 3 TOTAL BARE CONDUCTOR WEIGHT 50.786

WNDG	TURNS	LO TAP	HI TAP	LAYRS	T/L	LAYR INS	SEC. INS	BUILD
S1	25.0			3	11.0	1(.00001)	1(.00700)	.549
P1	100.0	90.0	105.0	5	21.0	1(.00001)	1(.00001)	.517

TOTAL BUILD(%) 89.82

WNDG	TAPS: TURNS(VOLTS)		
P1	92.5(444.00)	95.0(456.00)	97.5(468.00)
	102.5(492.00)	105.0(504.00)	

WNDG	INTERNAL DUCTS(95.00) %EFF	EXTERNAL DUCTS(95.00) %EFF
S1	1 .563 X .563 IN. END	
P1	2 .563 X .563 IN. END	.563 X .563 IN. END

WNDG	INT. DUCT AREA	EXT. DUCT AREA	TOTAL DUCT AREA
S1	147.2432	80.0211	227.2643
P1	371.1016	365.4896	736.5912

ELECTRICAL ANALYSIS

WNDG	FULL-LOAD VOLTS		TAP VOLTS LOW	HIGH	TEST KV	LOAD CURRENT	RESIST. @20 C.	CURRNT DENS.	%REG
P1	480.00	D	432.00	504.00	4.0	53.987	.10566	1585.	
S1	116.02	W			4.0	208.180	.00506	1765.	3.4

	F.L.	N.L.		
FLUX DENS.	15.398	15.691	LEAKAGE INDUCTANCE MHYS	.737
CORE LOSS	300.676	312.222	POWER FACTOR	1.0000
COIL LOSS	2559.344	.136	IMPEDANCE %	4.54
EXCIT. VA	752.681	761.771	EFFICIENCY %	96.32
EXCIT. CURR.	.523	.529	OPEN ALT. DUCT 3	.00

AMBIENT TEMP.	20.00	NOMINAL LENGTH	18.75
TEMP.RISE	150.00	NOMINAL DEPTH	12.48
OPERATING TEMP.	170.00	NOMINAL HEIGHT	16.56

WINDING: S1 P1

TEMP RISE: 150. 150.

2

```
 COND. I R LOSS          =   2478.1850
 COND. EDDY CURRENT LOSS =      6.8138
 OTHER STRAY LOSS        =     74.3455
 K VALUE                 =      1.0000
```

```
  WIRE WRAP PER COIL
WNDG   THICKNESS   WEIGHT
-------------------------
P1       .00500    .43372
S1       .00500    .13070
```

%LOAD	%REG	%EFF	%IR	%IX	%IZ	COIL LOSS	TEMP. RISE
25	.58	97.79	.582	.772	.967	113.283	38.5
35	.83	98.00	.826	1.078	1.358	224.670	42.8
50	1.23	97.96	1.219	1.541	1.964	473.697	52.4
65	1.69	97.70	1.663	2.008	2.607	840.287	66.5
75	2.04	97.45	2.001	2.322	3.065	1166.596	79.1
100	3.20	96.52	3.089	3.125	4.394	2402.231	127.1
125	5.06	94.91	4.857	3.970	6.273	4728.370	216.0

Table 5.6.3 provides the bill of materials which was calculated from the OPS design details report. This bill of materials uses the raw material prices given in this Chapter for fixed and variable materials used in building the transformer. These materials are then marked-up at the bottom of the table to arrive at the manufacturer's selling price. This table provides the bill of materials for a non-evaluated transformer from design line 7, a 75kVA three-phase, low-voltage, dry-type M6 design, with an aluminum primary and an aluminum secondary. This design uses a butt-lap core configuration, and was generated using a $0.00A and $0.00B.

Table 5.6.3 Bill of Materials for Non-Evaluated Transformer from Design Line 7

Bill of Materials and Labor for low, voltage, dry-type, 3-phase, 75kVA				
A$ Input	$0.00			
B$ Input	$0.00			
Efficiency at 35% load	97.98%			
Material item	**Type**	**quantity**	**$ each**	**$ total**
Core Steel* (lb)	M6-.014	309	$ 0.70	$ 216.40
Primary winding* (lb)	Aluminum wire, rectangular 0.1 x 0.2, Nomex w	32	$ 2.06	$ 66.38
Secondary winding* (lb)	Aluminum wire, rectangular 0.1 x 0.2, Nomex w	19	$ 2.06	$ 38.11
Winding form & insulation* (lb)	Nomex insulation	1	$ 18.11	$ 24.03
Enclosure	14-gauge steel	1	$ 123.75	$ 123.75
Core Clamp	-	1	$ 19.00	$ 19.00
Duct Spacers	-	19	$ 0.32	$ 5.95
Nameplate	-	1	$ 0.65	$ 0.65
LV Buss Bar (ft.)	-	7	$ 1.50	$ 10.50
HV Terminal Board	-	3	$ 9.00	$ 27.00
Impregnation (gal.)	-	0.8	$ 17.80	$ 14.93
Misc. Hardware	-	1	$ 7.00	$ 7.00
Scrap factor		1.0%		$ 3.45
Total Material Cost				$ 557.16
Labor item		**hours**	**rate**	**$ total**
Lead dressing		0.25	42.77	$ 10.69
Inspection		0.05	42.77	$ 2.14
Preliminary test		0.05	42.77	$ 2.14
Final test		0.10	42.77	$ 4.28
Packing		0.20	42.77	$ 8.55
Marking and miscellaneous		0.20	42.77	$ 8.55
Enclosure manufacturing		1.50	42.77	$ 64.16
Winding the primary		0.47	42.77	$ 20.21
Winding the secondary		0.83	42.77	$ 35.29
Core stacking		1.81	42.77	$ 77.39
Core assembly		1.00	42.77	$ 42.77
Handling and slitting factor (on material)		1.50%		$ 5.17
Total Labor		6.46	42.77	$ 281.34
Manufacturing Cost (Material + Labor)				$ 838.49
Factory Overhead (Materials only)		12.5%		$ 69.64
Non-production Cost Markup		25.0%		$ 227.03
Manufacturer Selling Price				$1,135.17

* indicates those items to which the scrap factor (1.0%) and the handling and slitting factor (1.5%) are applied.

This bill of materials is based on non-rounded core dimensions.

Figure 5.6.3 provides a summary of the costs contributing to the total selling price of the non-evaluated transformer from design line 7. For this design, approximately 49 percent of the final manufacturer selling price is direct material and scrap. Labor accounts for 25 percent of the price, and together, the factory overhead and selling price account for 26 percent.

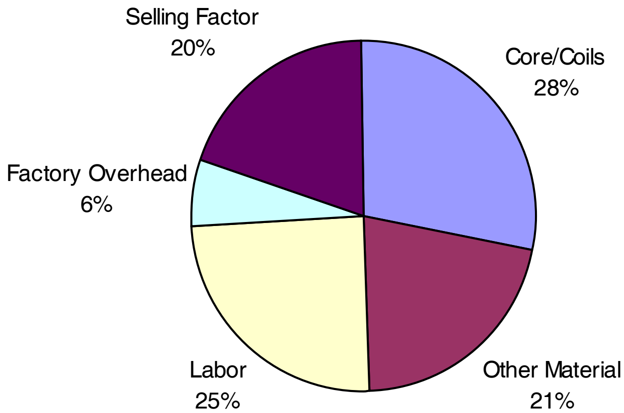

Figure 5.6.3 Manufacturer Selling Price Breakdown, Non-Evaluated Transformer from Design Line 7

5.6.4 Design Details Report for Evaluated Transformer from Design Line 7

A design specification report for a 75kVA three-phase, low-voltage, dry-type transformer appears below. This design incorporates M6 t-mitered core steel, with an aluminum primary and an aluminum secondary. The evaluation factors for this design are $1.50 A and $0.14 B. The bill of materials and associated breakdown of costs for this design are also reported, after the design and electrical analysis reports

```
OPTIMIZED PROGRAM SERVICE

                   CLEVELAND OHIO            101800
                       2005- 3-12     4:44: 4
STRIP         3-PHASE TYPE TRANSFORMER                L7M6ALALTMiter

FREQUENCY     60.0            KVA RATING     74.94 @ 100.00% DUTY CYCLE

CORE  3.422" STRP  STACK  4.599             GRADE M 6    THICKNESS .0140

WINDOW:   3.705 X 10.874     EFF. AREA   15.188    WEIGHT   296.940

WINDING FORM:INS. DIM.  3.547 X  4.724  THICKNESS  .070  LENGTH 10.749
```

COIL SPECIFICATIONS

WNDG	WIRE	LENGTH	MEAN TURNS	MARGIN	WT
S1	1X 2(.1456X .5826) AL	50.65	20.26	.250	9.974
P1	.1278X .3835 AL	324.87	30.94	.250	18.351

NUMBER OF COILS 3 TOTAL BARE CONDUCTOR WEIGHT 84.975

WNDG	TURNS	LO TAP	HI TAP	LAYRS	T/L	LAYR INS	SEC. INS	BUILD
S1	30.0			4	7.5	1(.00001)	1(.00700)	.623
P1	120.0	108.0	126.0	6	24.0	1(.00001)	1(.00001)	.827

TOTAL BUILD(%) 85.80

WNDG	TAPS: TURNS(VOLTS)		
P1	111.0(444.00)	114.0(456.00)	117.0(468.00)
	123.0(492.00)	126.0(504.00)	

WNDG	INTERNAL DUCTS(95.00) %EFF	EXTERNAL DUCTS(95.00) %EFF
S1	1 .563 X .563 IN. END	
P1	2 .563 X .563 IN. END	.563 X .563 IN. END

WNDG	INT. DUCT AREA	EXT. DUCT AREA	TOTAL DUCT AREA
S1	99.2988	58.5992	157.8980
P1	319.1871	402.3261	721.5132

ELECTRICAL ANALYSIS

WNDG	FULL-LOAD VOLTS		TAP VOLTS LOW	HIGH	TEST KV	LOAD CURRENT	RESIST. @20 C.	CURRNT DENS.	%REG
P1	480.00	D	432.00	504.00	4.0	53.640	.09004	1113.	
S1	116.64	W			4.0	208.180	.00403	1239.	2.8

	F.L.	N.L.		
FLUX DENS.	15.063	15.314	LEAKAGE INDUCTANCE MHYS	1.065
CORE LOSS	239.558	247.624	POWER FACTOR	1.0000
COIL LOSS	2111.250	.042	IMPEDANCE %	5.25
EXCIT. VA	444.479	459.371	EFFICIENCY %	96.96
EXCIT. CURR.	.309	.319	OPEN ALT. DUCT 3	.00

AMBIENT TEMP.	20.00	NOMINAL LENGTH	21.38
TEMP.RISE	150.00	NOMINAL DEPTH	12.93
OPERATING TEMP.	170.00	NOMINAL HEIGHT	17.72

WINDING: S1 P1

TEMP RISE: 150. 150.

2

```
 COND. I R LOSS           =   2037.1360
 COND. EDDY CURRENT LOSS =     12.9997
 OTHER STRAY LOSS         =     61.1141
 K VALUE                  =      1.0000
```

```
  WIRE WRAP PER COIL
WNDG   THICKNESS   WEIGHT
-------------------------
P1      .00500    .57064
S1      .00500    .25054
```

%LOAD	%REG	%EFF	%IR	%IX	%IZ	COIL LOSS	TEMP. RISE
25	.48	98.22	.479	1.110	1.209	93.850	38.4
35	.69	98.38	.680	1.552	1.694	186.261	42.7
50	1.03	98.33	1.004	2.217	2.434	392.678	52.3
65	1.42	98.11	1.370	2.889	3.197	696.014	66.4
75	1.72	97.90	1.647	3.340	3.724	965.461	78.9
100	2.68	97.12	2.537	4.488	5.155	1980.615	126.4
125	4.21	95.80	3.962	5.684	6.928	3867.327	213.4

Table 5.6.4 provides the bill of materials which was calculated from the OPS design details report. This bill of materials uses the raw material prices given in this Chapter for fixed and variable materials used in building the transformer. These materials are then marked-up at the bottom of the table to arrive at the manufacturer's selling price. This table provides the bill of materials for an evaluated transformer from design line 7, a 75kVA three-phase, low-voltage dry-type M6 design, with an aluminum primary and an aluminum secondary. This design uses a "scrapless" t-mitered core construction, and was generated using a $0.00A and $0.00B. Note that the M6 core steel incorporates a $0.05 per pound mark-up to account for costs associated with tooling for the t-mitering core-cutting equipment.

Table 5.6.4 Bill of Materials for Evaluated Transformer frm Design Line 7

Bill of Materials and Labor for low, voltage, dry-type, 3-phase, 75kVA				
A$ Input	$1.50			
B$ Input	$0.14			
Efficiency at 35% load	98.36%			
Material item	**Type**	**quantity**	**$ each**	**$ total**
Core Steel* (lb)	M6-.014	297	$ 0.75	$ 222.71
Primary winding* (lb)	Aluminum wire, rectangular 0.1 x 0.2, Nomex w	55	$ 2.06	$ 113.26
Secondary winding* (lb)	Aluminum wire, rectangular 0.1 x 0.2, Nomex w	30	$ 2.06	$ 61.56
Winding form & insulation* (lb)	Nomex insulation	1	$ 18.11	$ 25.76
Enclosure	14-gauge steel	1	$ 126.26	$ 126.26
Core Clamp	-	1	$ 19.00	$ 19.00
Duct Spacers	-	21	$ 0.32	$ 6.88
Nameplate	-	1	$ 0.65	$ 0.65
LV Buss Bar (ft.)	-	7	$ 1.50	$ 10.50
HV Terminal Board	-	3	$ 9.00	$ 27.00
Impregnation (gal.)	-	1.1	$ 17.80	$ 18.87
Misc. Hardware	-	1	$ 7.00	$ 7.00
Scrap factor		1.0%		$ 4.23
Total Material Cost				$ 643.67
Labor item		**hours**	**rate**	**$ total**
Lead dressing		0.25	42.77	$ 10.69
Inspection		0.05	42.77	$ 2.14
Preliminary test		0.05	42.77	$ 2.14
Final test		0.10	42.77	$ 4.28
Packing		0.20	42.77	$ 8.55
Marking and miscellaneous		0.20	42.77	$ 8.55
Enclosure manufacturing		1.50	42.77	$ 64.16
Winding the primary		0.57	42.77	$ 24.25
Winding the secondary		0.99	42.77	$ 42.34
Core stacking		1.61	42.77	$ 68.84
Core assembly		1.00	42.77	$ 42.77
Handling and slitting factor (on material)		1.50%		$ 6.35
Total Labor		6.52	42.77	$ 285.07
Manufacturing Cost (Material + Labor)				$ 928.74
Factory Overhead (Materials only)		12.5%		$ 80.46
Non-production Cost Markup		25.0%		$ 252.30
Manufacturer Selling Price				$1,261.50

* indicates those items to which the scrap factor (1.0%) and the handling and slitting factor (1.5%) are applied.

This bill of materials is based on non-rounded core dimensions.

Figure 5.6.4 provides a summary of the costs contributing to the total selling price of the evaluated transformer from design line 7. For this design, approximately 51 percent of the final manufacturer selling price is direct material and scrap. Labor accounts for 23 percent of the price, and together, the factory overhead and selling price account for 26 percent.

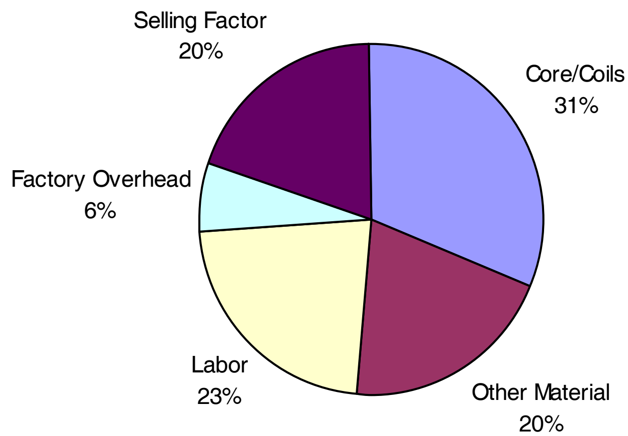

Figure 5.6.4 Manufacturer Selling Price Breakdown, Evaluated Transformer from Design Line 7

5.6.5 Design Details Report for Non-Evaluated Transformer from Design Line 12

The following design report provides information on one of several designs prepared to study the representative unit from design line 12. This is a 1500kVA, three-phase, medium-voltage, dry-type unit at 95kV BIL. The design shown here (out of the 2,590 designs in the database) is for M6 core steel with aluminum primary and secondary windings, and a $0.00A and $0.00B.

```
OPTIMIZED PROGRAM SERVICE

                   CLEVELAND OHIO            101800
                       2005- 3-12    12:58: 9
STRIP CRUC    3-PHASE TYPE TRANSFORMER                L12M6ALAL

FREQUENCY    60.0             MVA RATING      1.50 @ 100.00% DUTY CYCLE

CORE  9.929" CRUC  STACK  9.929            GRADE M 6    THICKNESS .0140

WINDOW:  14.442 X 50.208     EFF. AREA   75.247    WEIGHT  5565.141

WINDING FORM:INS. DIM. 10.457 X 10.457  THICKNESS  .156  LENGTH 48.208


                         COIL SPECIFICATIONS
                         -------------------

WNDG                WIRE            LENGTH   MEAN TURNS  MARGIN      WT
```

S1	2X 1(.0167X38.2076)	AL	46.38	42.82	5.000	69.450
P1	1X 2(.0668X .2318)	AL	3407.39	66.57	5.750	116.001

NUMBER OF COILS 3 TOTAL BARE CONDUCTOR WEIGHT 556.355

WNDG	TURNS	LO TAP	HI TAP	LAYRS	T/L	LAYR INS	SEC. INS	BUILD
S1	13.0			13	1.0	1(.01000)	1(.20000)	2.805
P1	585.0	555.8	614.3	15	1.0	1(.00001)	1(.00001)	1.182

TOTAL BUILD(%) 84.56

WNDG	TAPS: TURNS(VOLTS)		
P1	570.4(12158.25)	599.6(12781.75)	614.3(13093.50)

DISK INFORMATION

WNDG	DISK	WIDTH	VOLTS/DISK	BREAK	TAPS	SPACE
P1	42	.493	311.750	.750	2(.50)	38(.375)

WNDG	INTERNAL DUCTS(90.00)	%EFF	EXTERNAL DUCTS(90.00)	%EFF
S1	3 .750 X .750 IN.	FULL		
P1			2 .750 X .750 IN.	FULL

WNDG	INT. DUCT AREA	EXT. DUCT AREA	TOTAL DUCT AREA
S1	6800.8820	1617.2770	8418.1580
P1	.0000	2519.9360	5176.6380

ELECTRICAL ANALYSIS

WNDG	FULL-LOAD VOLTS		TAP VOLTS LOW	HIGH	TEST KV	LOAD CURRENT	RESIST. @20 C.	CURRNT DENS.	%REG
P1	12470.00	D	11846.50	13093.50	18.0	40.735	1.56703	1402.	
S1	273.07	W			4.0	1804.300	.00049	1412.	1.4

	F.L.	N.L.		
FLUX DENS.	16.320	16.472	LEAKAGE INDUCTANCE MHYS	45.571
CORE LOSS	4645.135	4734.112	POWER FACTOR	1.0000
COIL LOSS	19994.840	.493	IMPEDANCE %	5.76
EXCIT. VA	8824.361	9869.501	EFFICIENCY %	98.38
EXCIT. CURR.	.236	.264	OPEN ALT. DUCT 3	.00

AMBIENT TEMP.	20.00	NOMINAL LENGTH	73.11
TEMP.RISE	141.46	NOMINAL DEPTH	22.49
OPERATING TEMP.	161.46	NOMINAL HEIGHT	70.06

```
     CRUCIFORM PLATE WIDTHS

       W1     W2     W3     W4     W5
    9.929  8.843  7.394  5.579  3.281

     STACK HEIGHTS

       H1     H2     H3     H4     H5
    3.283  1.149   .907   .725   .542

     RESULTANT GROSS AREA:   77.977   CIRCLE AREA FILL: % 90.8

     MIN.  WINDING FORM INSIDE DIAMETER:  10.457

 WINDING:        S1   P1

 TEMP RISE:  141. 116.

        2
 COND. I R LOSS          =  19188.2900
 COND. EDDY CURRENT LOSS =     39.0233
 OTHER STRAY LOSS        =    767.5314
 K VALUE                 =      1.0000


TEMP. AT LOW TAP
----------------
S1     141.46
P1     121.72

  WIRE WRAP PER COIL
WNDG   THICKNESS   WEIGHT
-------------------------
P1      .00600   8.72106


                             o
AT REFERENCE TEMP.     170.0
----------------------------
COIL LOSS   = 20441.770
IMPEDANCE % =     5.763
```

%LOAD	%REG	%EFF	%IR	%IX	%IZ	COIL LOSS	TEMP. RISE
25	.25	98.51	.241	1.402	1.423	944.956	47.0
35	.36	98.76	.344	1.958	1.988	1890.136	54.1
50	.55	98.85	.514	2.794	2.841	4033.891	68.2
65	.78	98.79	.708	3.634	3.702	7212.068	86.3
75	.94	98.71	.852	4.196	4.282	10014.870	100.3
100	1.44	98.38	1.275	5.612	5.755	19994.840	141.5
125	2.08	97.91	1.805	7.048	7.275	35411.180	190.8

Table 5.6.5 provides the bill of materials which was calculated from the OPS design details report. This bill of materials uses the raw material prices given in this Chapter for fixed and variable materials used in building the transformer. These materials are then marked-up at the bottom of the table to arrive at the manufacturer’s selling price. This table provides the bill of materials for a non-

evaluated transformer from design line 12, a 1500kVA three-phase, medium-voltage, dry-type design with M6 core steel and an aluminum primary and secondary. This design was generated using a $0.00A and $0.00B.

Table 5.6.5 Bill of Materials for Non-Evaluated Transformer from Design Line 12

Bill of Materials and Labor for medium voltage, dry-type, 3-phase, 1500kVA				
A$ Input	$0.00			
B$ Input	$0.00			
Efficiency at 50% load	98.81%			
Material item	**Type**	**quantity**	**$ each**	**$ total**
Core steel* (lb)	M6-.014	5565	$ 0.70	$ 3,895.60
Primary winding* (lb)	Aluminum wire, rectangular 0.1 x 0.2, Nomex w	348	$ 2.06	$ 715.95
Secondary winding* (lb)	Aluminum strip, thickness range 0.02-0.045	208	$ 1.54	$ 321.35
Winding form & insulation* (lb)	Nomex insulation	110	$ 18.11	$ 1,997.39
Enclosure	12-gauge steel	1	$ 748.06	$ 748.06
Core clamp	-	1	$ 125.00	$ 125.00
Nameplate	-	1	$ 0.65	$ 0.65
LV buss bar (ft.)	-	16	$ 12.00	$ 192.00
HV tap board	-	3	$ 9.00	$ 27.00
HV terminals	-	1	$ 135.00	$ 135.00
Winding combs (lb.)	-	70	$ 10.24	$ 717.80
Duct spacers (ft.)		1318	$ 0.56	$ 738.24
Impregnation (gal.)	-	25	$ 17.80	$ 443.74
Misc. hardware	-	1	$ 54.00	$ 54.00
Scrap factor		1.0%		$ 69.30
Additional scrap on core**		4.0%		$ 155.82
Total Material Cost				$10,336.91
Labor item		**hours**	**rate**	**$ total**
Lead dressing		1.00	42.77	$ 42.77
Inspection		0.25	42.77	$ 10.69
Preliminary test		0.50	42.77	$ 21.39
Final test		0.75	42.77	$ 32.08
Packing		2.00	42.77	$ 85.54
Enclosure manufacturing		8.00	42.77	$ 342.16
Marking and miscellaneous		2.20	42.77	$ 94.09
Winding the primary		23.03	42.77	$ 985.18
Winding the secondary		2.93	42.77	$ 125.10
Core stacking		7.94	42.77	$ 339.73
Core assembly		6.00	42.77	$ 256.62
Handling and Slitting Factor (on material)		1.50%		$ 103.95
Total Labor		54.603	42.77	$ 2,439.31
Manufacturing Cost (Material + Labor)				$12,776.21
Factory Overhead (Materials only)		12.5%		$ 1,292.11
Non-production Cost Markup		25.0%		$ 3,517.08
Manufacturer Selling Price				$17,585.41

* indicates those items to which the scrap factor (1.0%) and the handling and slitting factor (1.5%) are applied.
** additional scrap on core due to mitering process.

This bill of materials is based on non-rounded core dimensions.

Figure 5.6.5 provides a summary of the costs contributing to the total selling price of the non-evaluated transformer from design line 12. For this design, approximately 59 percent of the final manufacturer selling price is direct material and scrap. Labor accounts for 14 percent of the price, and together, the factory overhead and selling price account for 27 percent.

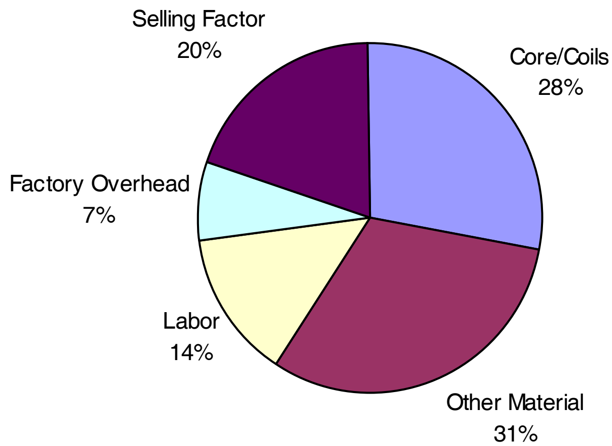

Figure 5.6.5 Manufacturer Selling Price Breakdown, Non-Evaluated Transformer from Design Line 12

5.6.6 Design Details Report for Evaluated Transformer from Design Line 12

A design specification report for a 1500kVA three-phase, medium-voltage, dry-type transformer appears below. This design incorporates M3 core steel, with copper primary and secondary windings. The evaluation factors for this design are $0.50 A and $0.08 B. The bill of materials and associated breakdown of costs for this design are also reported, after the design and electrical analysis reports

```
OPTIMIZED PROGRAM SERVICE

                   CLEVELAND OHIO            101800
                       2005- 3-12    19:22:57
STRIP CRUC    3-PHASE TYPE TRANSFORMER                L12M3CUCU

FREQUENCY    60.0             MVA RATING      1.50 @ 100.00% DUTY CYCLE

CORE  9.936" CRUC  STACK  9.936            GRADE M 3    THICKNESS .0090

WINDOW:  13.354 X 50.940     EFF. AREA   74.572    WEIGHT  5550.538

WINDING FORM:INS. DIM. 10.464 X 10.464  THICKNESS  .156  LENGTH 48.940

                         COIL SPECIFICATIONS
                         -------------------

WNDG             WIRE            LENGTH   MEAN TURNS  MARGIN      WT
----------------------------------------------------------------------
```

S1	2X 1(.0096X38.9404)	CU	45.72	42.20	5.000	129.011
P1	1X 2(.0512X .1778)	CU	3301.91	64.51	5.750	226.486

NUMBER OF COILS 3 TOTAL BARE CONDUCTOR WEIGHT 1075.046

WNDG	TURNS	LO TAP	HI TAP	LAYRS	T/L	LAYR INS	SEC. INS	BUILD
S1	13.0			13	1.0	1(.01000)	1(.20000)	2.620
P1	585.0	555.8	614.3	15	1.0	1(.00001)	1(.00001)	.948

TOTAL BUILD(%) 85.20

WNDG	TAPS: TURNS(VOLTS)		
P1	570.4(12158.25)	599.6(12781.75)	614.3(13093.50)

DISK INFORMATION

WNDG	DISK	WIDTH	VOLTS/DISK	BREAK	TAPS	SPACE
P1	42	.510	311.750	.750	2(.50)	38(.375)

WNDG	INTERNAL DUCTS(90.00)	%EFF	EXTERNAL DUCTS(90.00)	%EFF
S1	3 .750 X .750 IN.	FULL		
P1			2 .750 X .750 IN.	FULL

WNDG	INT. DUCT AREA	EXT. DUCT AREA	TOTAL DUCT AREA
S1	6962.6350	1621.1610	8583.7960
P1	.0000	2516.7880	4898.1040

ELECTRICAL ANALYSIS

WNDG	FULL-LOAD VOLTS	TAP VOLTS LOW	HIGH	TEST KV	LOAD CURRENT	RESIST. @20 C.	CURRNT DENS.	%REG
P1	12470.00 D	11846.50	13093.50	18.0	40.680	1.51120	2286.	
S1	273.23 W			4.0	1804.300	.00050	2411.	1.4

	F.L.	N.L.		
FLUX DENS.	16.477	16.622	LEAKAGE INDUCTANCE MHYS	44.500
CORE LOSS	3261.498	3377.035	POWER FACTOR	1.0000
COIL LOSS	19285.360	.285	IMPEDANCE %	5.61
EXCIT. VA	7133.554	7726.391	EFFICIENCY %	98.52
EXCIT. CURR.	.191	.207	OPEN ALT. DUCT 3	.00

AMBIENT TEMP.	20.00	NOMINAL LENGTH	69.87
TEMP.RISE	138.10	NOMINAL DEPTH	21.58
OPERATING TEMP.	158.10	NOMINAL HEIGHT	70.81

CRUCIFORM PLATE WIDTHS

```
      W1     W2     W3     W4     W5
    9.936  8.849  7.399  5.583  3.284

     STACK HEIGHTS

      H1     H2     H3     H4     H5
    3.285  1.150   .907   .726   .542

     RESULTANT GROSS AREA:   78.085   CIRCLE AREA FILL: % 90.8

     MIN.  WINDING FORM INSIDE DIAMETER:  10.465

 WINDING:       S1   P1

 TEMP RISE:  138. 117.

       2
 COND. I R LOSS          =  18519.0200
 COND. EDDY CURRENT LOSS =     25.5813
 OTHER STRAY LOSS        =    740.7608
 K VALUE                 =      1.0000


TEMP. AT LOW TAP
----------------
S1     138.10
P1     122.59

  WIRE WRAP PER COIL
WNDG   THICKNESS   WEIGHT
-------------------------
P1      .00600   6.62868


                            o
AT REFERENCE TEMP.     170.0
----------------------------
COIL LOSS   = 19877.280
IMPEDANCE % =     5.620
```

%LOAD	%REG	%EFF	%IR	%IX	%IZ	COIL LOSS	TEMP. RISE
25	.24	98.88	.232	1.364	1.384	907.508	41.9
35	.35	99.03	.332	1.907	1.935	1818.703	49.2
50	.53	99.05	.497	2.723	2.768	3887.590	63.8
65	.75	98.96	.684	3.542	3.608	6955.772	82.2
75	.91	98.86	.823	4.091	4.173	9660.987	96.4
100	1.39	98.52	1.231	5.473	5.610	19285.400	138.1
125	2.00	98.05	1.742	6.873	7.090	34129.490	187.9

Table 5.6.6 provides the bill of materials which was calculated from the OPS design details report. This bill of materials uses the raw material prices given in this Chapter for fixed and variable materials used in building the transformer. These materials are then marked-up at the bottom of the table to arrive at the manufacturer's selling price. This table provides the bill of materials for an evaluated transformer from design line 12, a 1500kVA three-phase, medium-voltage, dry-type

transformer built with M3 core steel and copper primary and secondary windings. This design was generated using a $0.50A and $0.08B.

Figure 5.6.6 Bill of Materials for Evaluated Transformer from Design Line 12

Bill of Materials and Labor for medium voltage, dry-type, 3-phase, 1500kVA				
A$ Input		$0.50		
B$ Input		$0.08		
Efficiency at 50% load		99.02%		
Material item	**Type**	**quantity**	**$ each**	**$ total**
Core steel* (lb)	M3-.009	5551	$ 0.80	$ 4,440.43
Primary winding* (lb)	Copper wire, rectangular 0.1 x 0.2, Nomex wra	679	$ 2.00	$ 1,361.68
Secondary winding* (lb)	Copper strip, thickness range 0.02-0.045	387	$ 2.32	$ 897.92
Winding form & insulation* (lb)	Nomex insulation	110	$ 18.11	$ 1,997.49
Enclosure	12-gauge steel	1	$ 733.94	$ 733.94
Core clamp	-	1	$ 125.00	$ 125.00
Nameplate	-	1	$ 0.65	$ 0.65
LV buss bar (ft.)	-	16	$ 12.00	$ 192.00
HV tap board	-	3	$ 9.00	$ 27.00
HV terminals	-	1	$ 135.00	$ 135.00
Winding combs (lb.)	-	62	$ 10.24	$ 631.23
Duct spacers (ft.)	-	1306	$ 0.56	$ 731.11
Impregnation (gal.)	-	23	$ 17.80	$ 411.17
Misc. hardware	-	1	$ 54.00	$ 54.00
Scrap factor		1.0%		$ 86.98
Additional scrap on core**		4.0%		$ 177.62
Total Material Cost				$12,003.20
Labor item		**hours**	**rate**	**$ total**
Lead dressing		1.00	42.77	$ 42.77
Inspection		0.25	42.77	$ 10.69
Preliminary test		0.50	42.77	$ 21.39
Final test		0.75	42.77	$ 32.08
Packing		2.00	42.77	$ 85.54
Enclosure manufacturing		8.00	42.77	$ 342.16
Marking and miscellaneous		2.20	42.77	$ 94.09
Winding the primary		23.03	42.77	$ 985.18
Winding the secondary		2.93	42.77	$ 125.10
Core stacking		7.95	42.77	$ 339.97
Core assembly		6.00	42.77	$ 256.62
Handling and Slitting Factor (on material)		1.50%		$ 130.46
Total Labor		54.608	42.77	$ 2,466.05
Manufacturing Cost (Material + Labor)				$14,469.25
Factory Overhead (Materials only)		12.5%		$ 1,500.40
Non-production Cost Markup		25.0%		$ 3,992.41
Manufacturer Selling Price				$19,962.07

* indicates those items to which the scrap factor (1.0%) and the handling and slitting factor (1.5%) are applied.
** additional scrap on core due to mitering process.

This bill of materials is based on non-rounded core dimensions.

Figure 5.6.6 provides a summary of the costs contributing to the total selling price of the evaluated transformer from design line 12. For this design, approximately 60 percent of the final manufacturer selling price is direct material and scrap. Labor accounts for 12 percent of the price, and together, the factory overhead and selling price account for 28 percent.

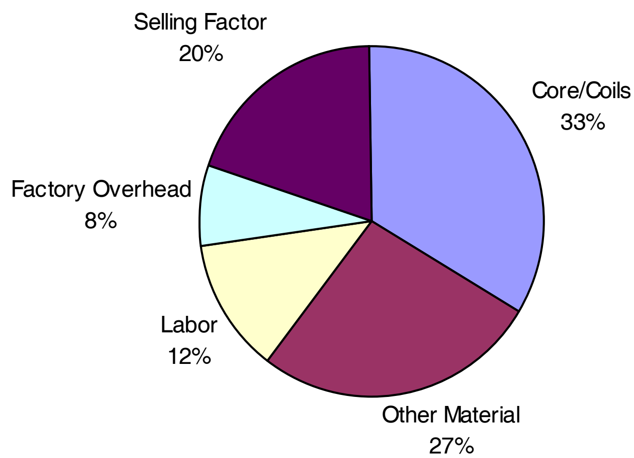

Figure 5.6.6 Manufacturer Selling Price Breakdown, Evaluated Transformer from Design Line 12

5.7 TEAR-DOWN ANALYSIS

The Department purchased, tested, disassembled and analyzed six transformers from design line 7 for the engineering analysis. This tear-down analysis was conducted for two reasons: 1) to demonstrate the predictive accuracy of the OPS software and 2) to validate the NOPR designs. Design line 7 was selected because it has the largest energy savings potential and because the representative unit (75 kVA three-phase low-voltage dry-type) is readily available from wholesale distributors. This section discusses the tear-down analysis on the six transformers and the results.

The Department purchased six transformers in early 2004, two ‘matched pairs’ from three manufacturers. The two transformers from each manufacturer represented a low first-cost unit and a NEMA TP-1 / Energy Star® unit. The transformers were shipped directly to the testing facility, Transformer Engineering Corporation (TEC) in Cleveland, Ohio. TEC has been a manufacturer of custom designed transformers, inductors, and other electro-magnetic components since 1937. TEC has a 50,000 square-foot facility in Cleveland, which includes a top-notch testing laboratory.

The Department reviewed several manufacturer catalogues and identified matched pairs of low-first cost and NEMA TP-1 units. These units were purchased from a local distributor, and shipped to TEC for testing. In Cleveland, the transformers were subjected to the following tests:

- Core loss test
- Conductor resistance
- Conductor loss test
- Temperature test

Data was recorded for each of these tests, documenting all the critical performance metrics for each of the six designs. The transformers were then carefully disassembled, with attention being paid to the construction techniques, including type of steel and conductor. All the pieces were weighed, and physical attributes such as core dimensions and number of turns were recorded. All of these physical dimensions were then put into the OPS software, to model the transformer that had just been disassembled. The OPS software then used its electrical analysis program to predict the values that had been measured in the laboratory. This step validated the predictive capability of the software for generating performance metrics associated with its modeled designs. The OPS software accurately predicted the efficiency (including the core and coil losses), the impedance, the inductance, and all the transformer performance metrics.

Next, when the NOPR engineering analysis designs were completed, the Department used the results of the tear-down analysis to create a manufacturer's selling price. In other words, using measured variables such as the pounds of core steel and pounds of conductor, the Department costed out the torn-down units using the same 2000-2004 average material prices and mark-ups, just as was done for the engineering analysis. The Department then plotted these six dots on the NOPR manufacturer's selling price-efficiency curve generated for design line 7. Figure 5.6.7 presents the plot of these torn-down units. The six transformer tear-downs align perfectly with the design line 7 cost-efficiency curve.

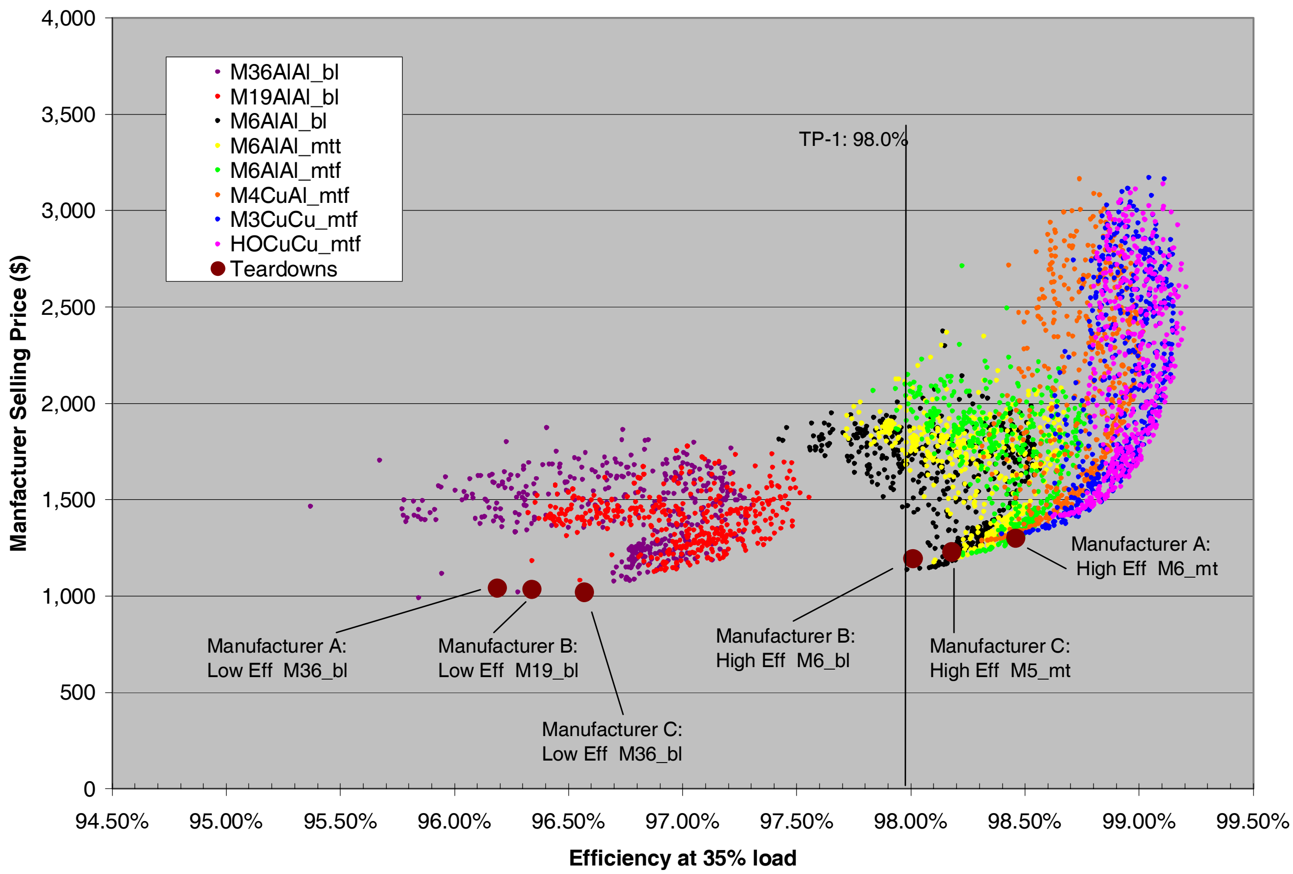

Figure 5.6.7 Tear-down Plot Comparison, Design Line 7, 75kVA Three-phase Dry-type